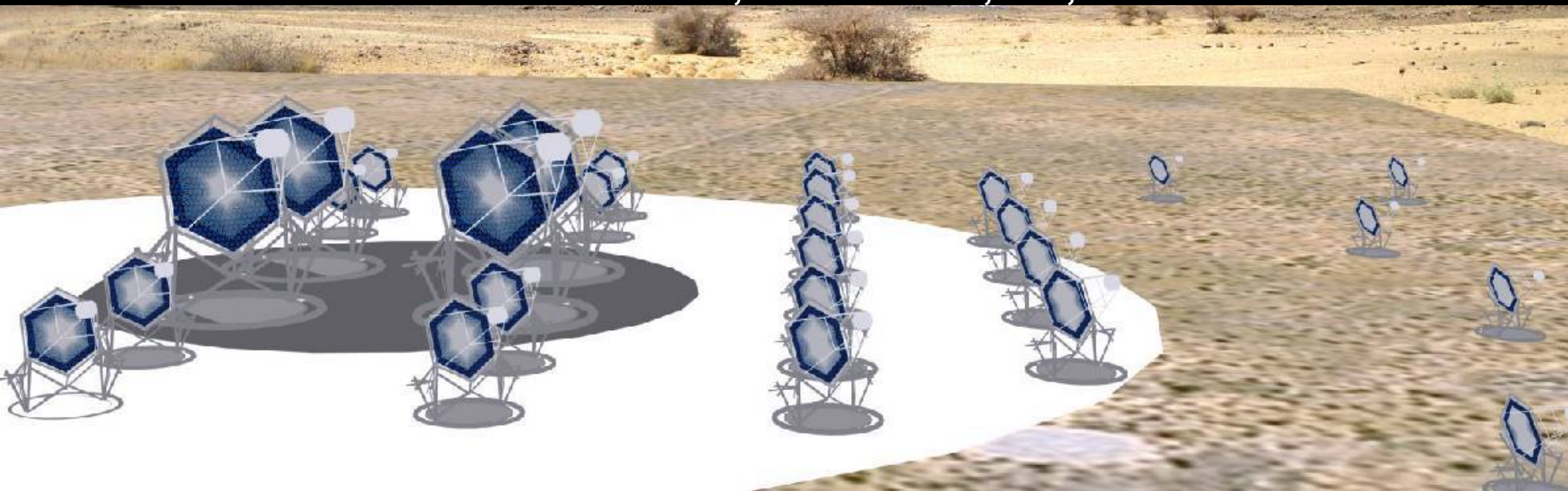
AGN Physics with the Cherenkov Telescope Array

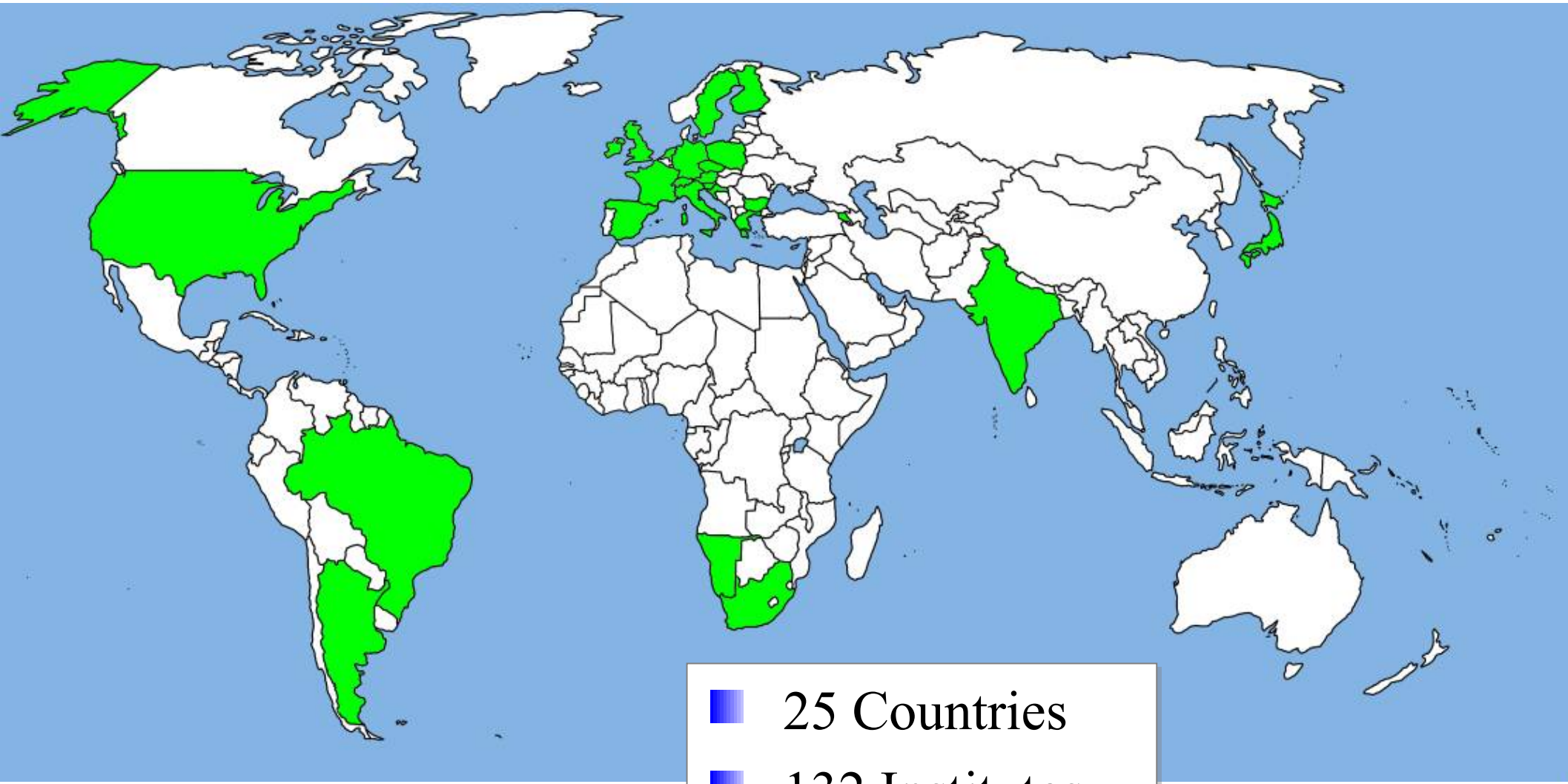
A. Zech (for the CTA Consortium)
LUTH, Observatoire de Paris

Fermi meets Jansky

November 2011, St. Michaels, MD, USA



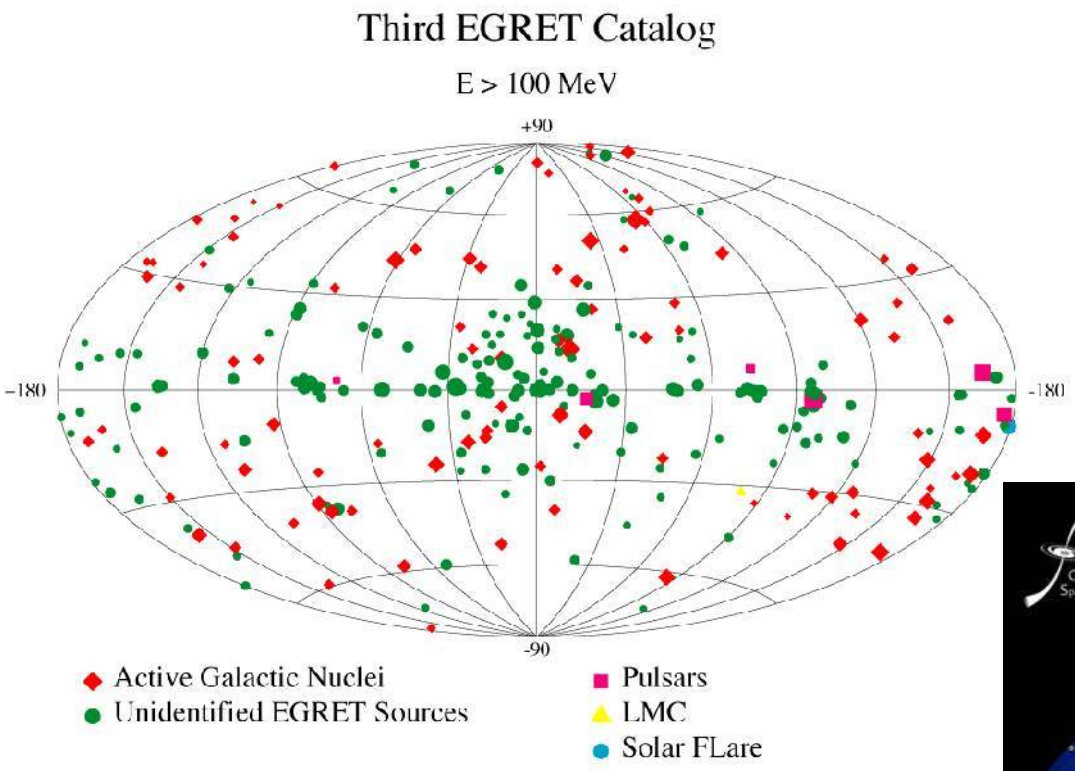
The CTA Consortium



- 25 Countries
- 132 Institutes
- >800 Persons

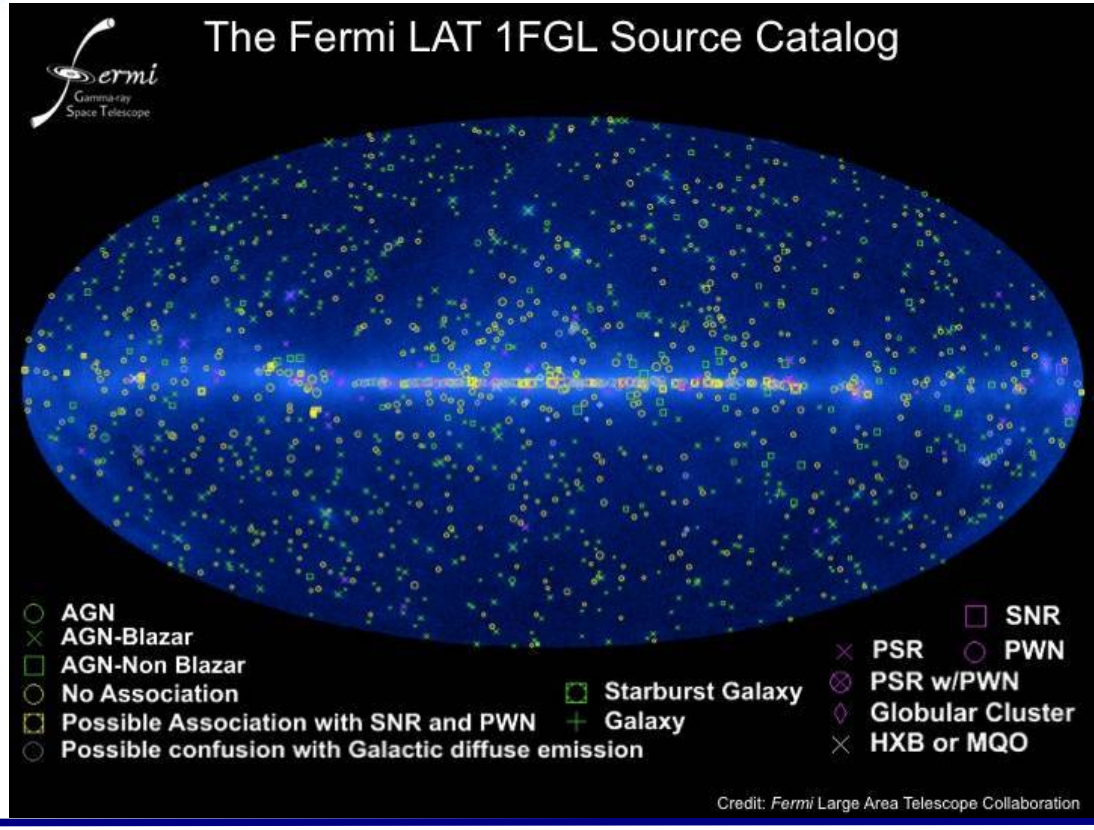
M. Martinez

GeV γ-ray astronomy: 1995 vs. 2010



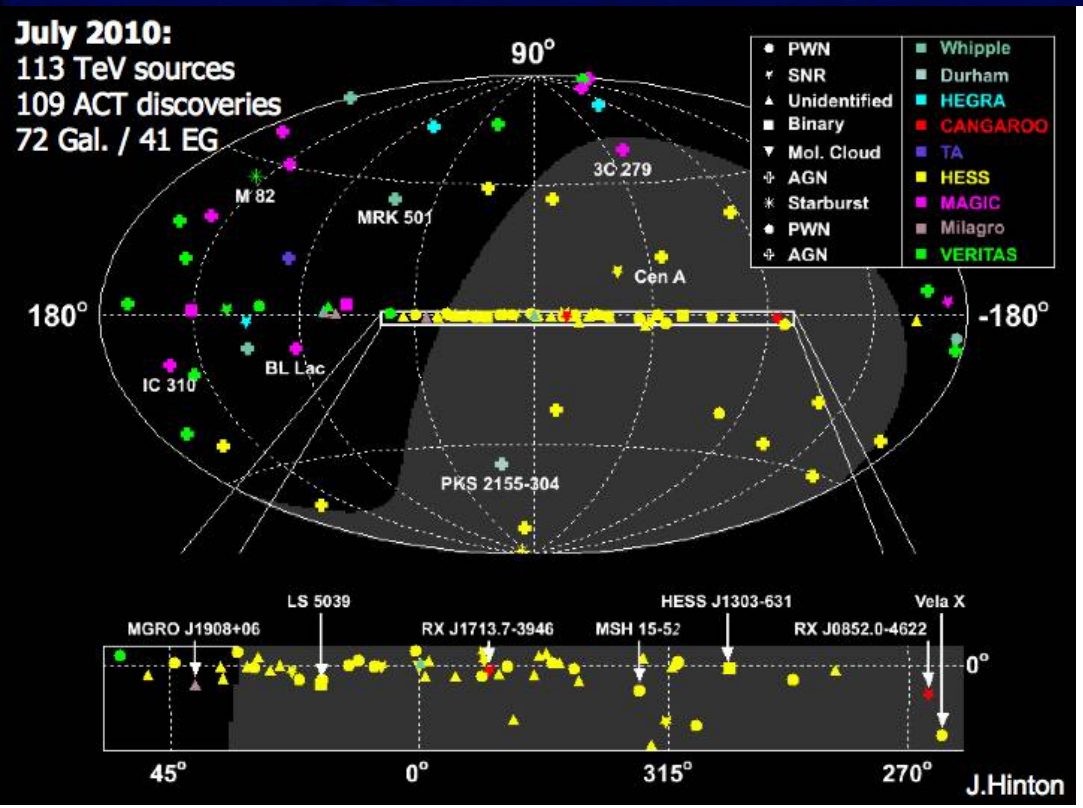
EGRET skymap 1995,
271 point sources

Fermi LAT skymap 2010,
1451 point sources



TeV γ-ray astronomy: 2010 vs. 2019

H.E.S.S. Gal. Plane Scan



VHE skymap 2010
(TeVCat: 130 VHE sources in Nov. 2011)

expected performance of CTA

- gain of factor 10 in sensitivity (mCrab)

- very large spectral coverage
(a few 10 GeV to a few 100 TeV)

- angular resolution down to arc-minute

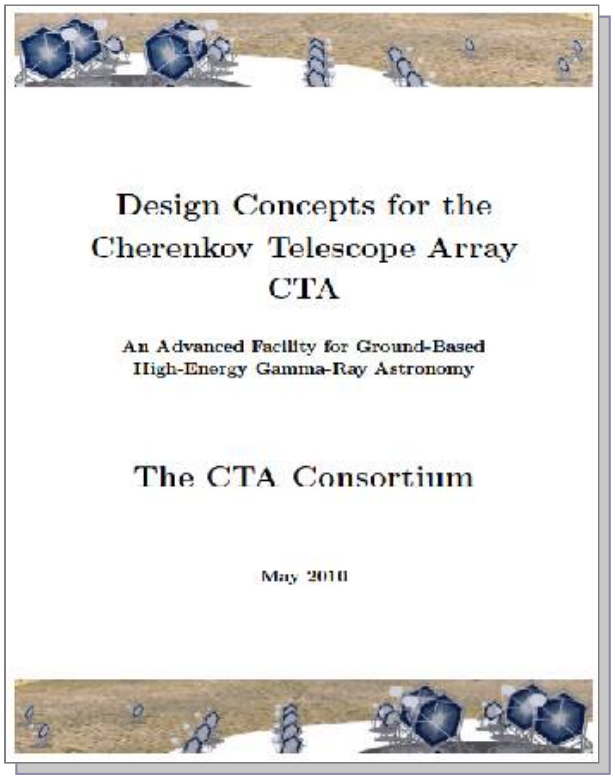
- full sky coverage

- different observation modes

=> towards 1000 VHE sources

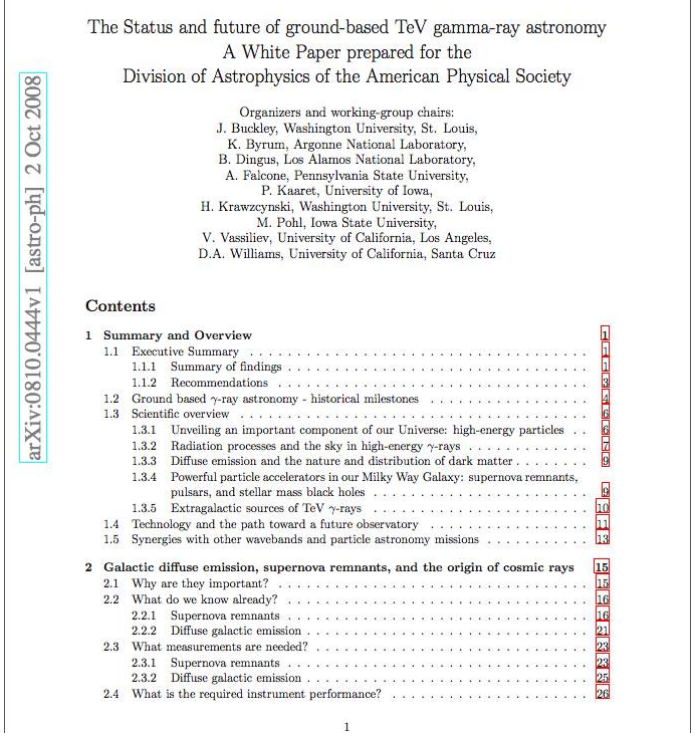
CTA/AGIS Simulations *Digel, Funk, Hinton*

CTA/AGIS Science Case: Publications



CTA Conceptual Design Report "Design Concepts for CTA", The CTA Consortium

(astro-ph/1008.3703)



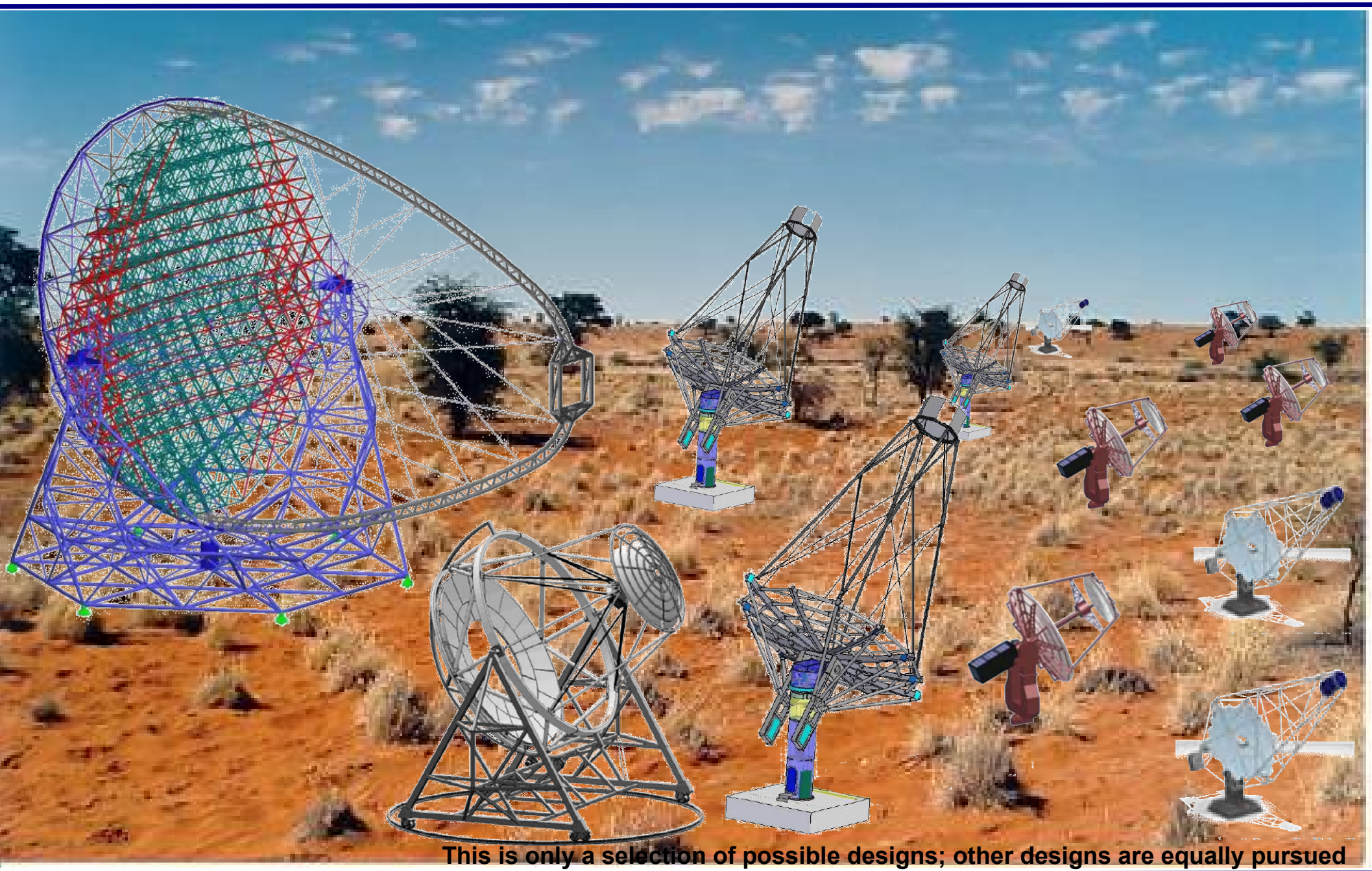
"The status and future of ground-based TeV gamma-ray astronomy. A White Paper for the Division of Astrophysics of the American Physical Society", J. Buckley et al.

(astro-ph/0810.0444)

A Special Issue of the **Astroparticle Physics** journal dedicated to the CTA Science Case is in preparation.

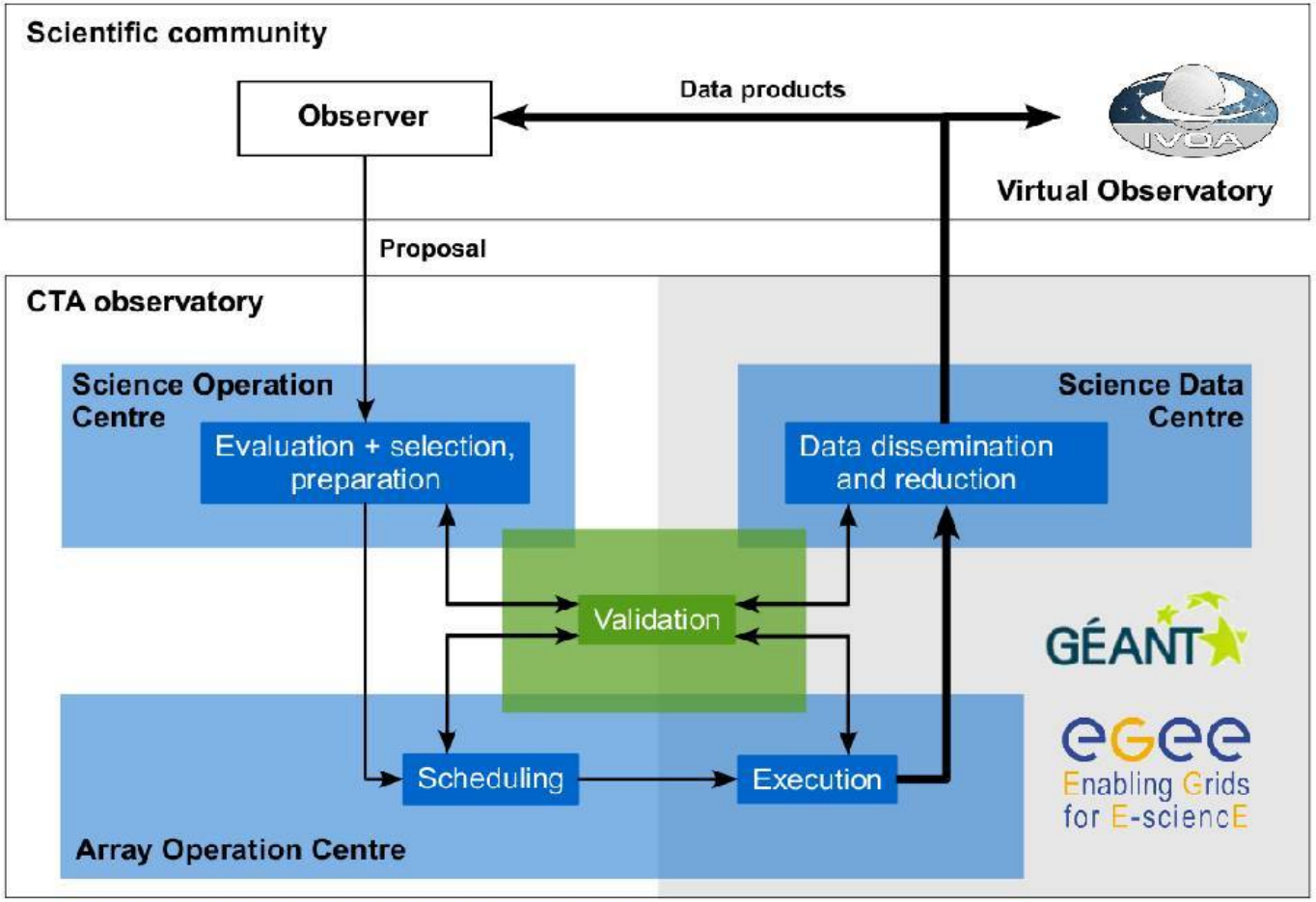
(AGN Science Case:
- review paper by *M. Böttcher, A. Reimer*
- "AGN under the scrutiny of CTA", *H.Sol, AZ, C.Boisson et al. for CTA Consortium*)

CTA in its Preparatory Phase



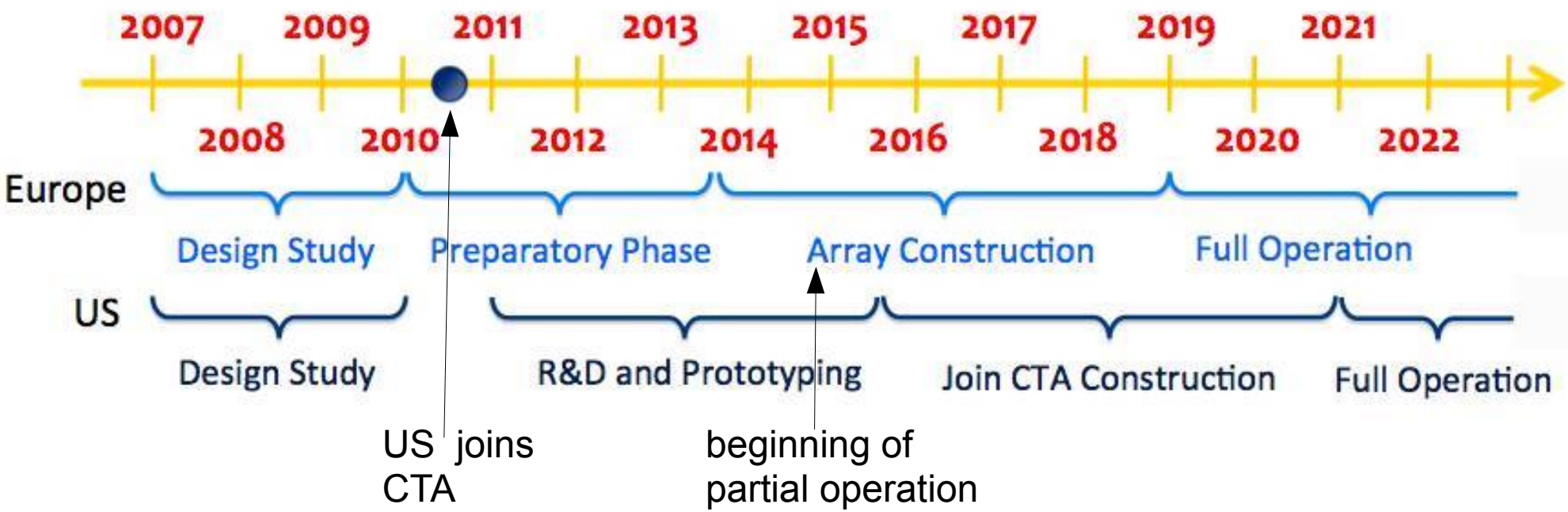
The first VHE OBSERVATORY

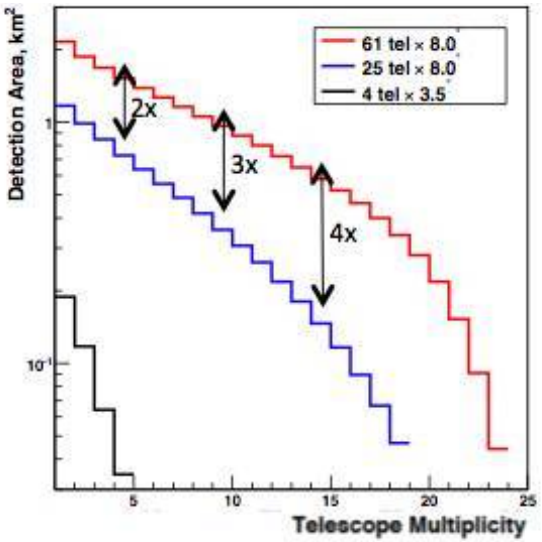
- CTA: first VHE observatory open to the community, with sites on both hemispheres.
- Program of observations based on proposals.
- Data and tools for data reduction will be provided to the observer.



from the Conceptual Design Report

CTA Timeline





Figures from S. Bugaev

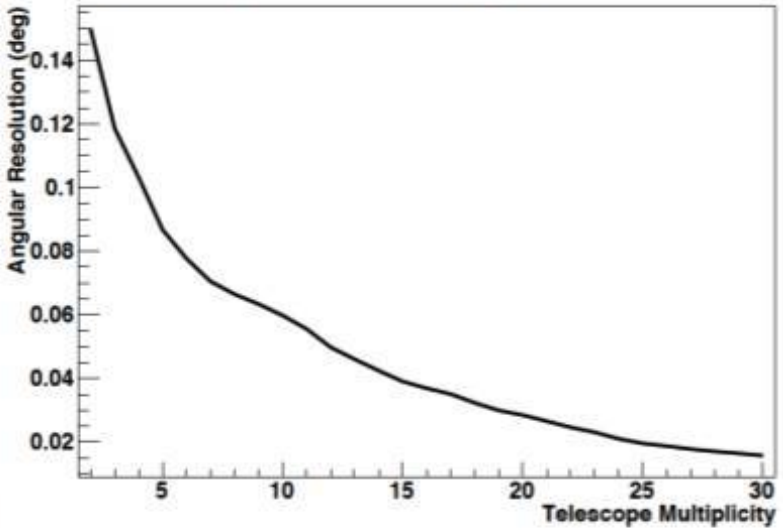
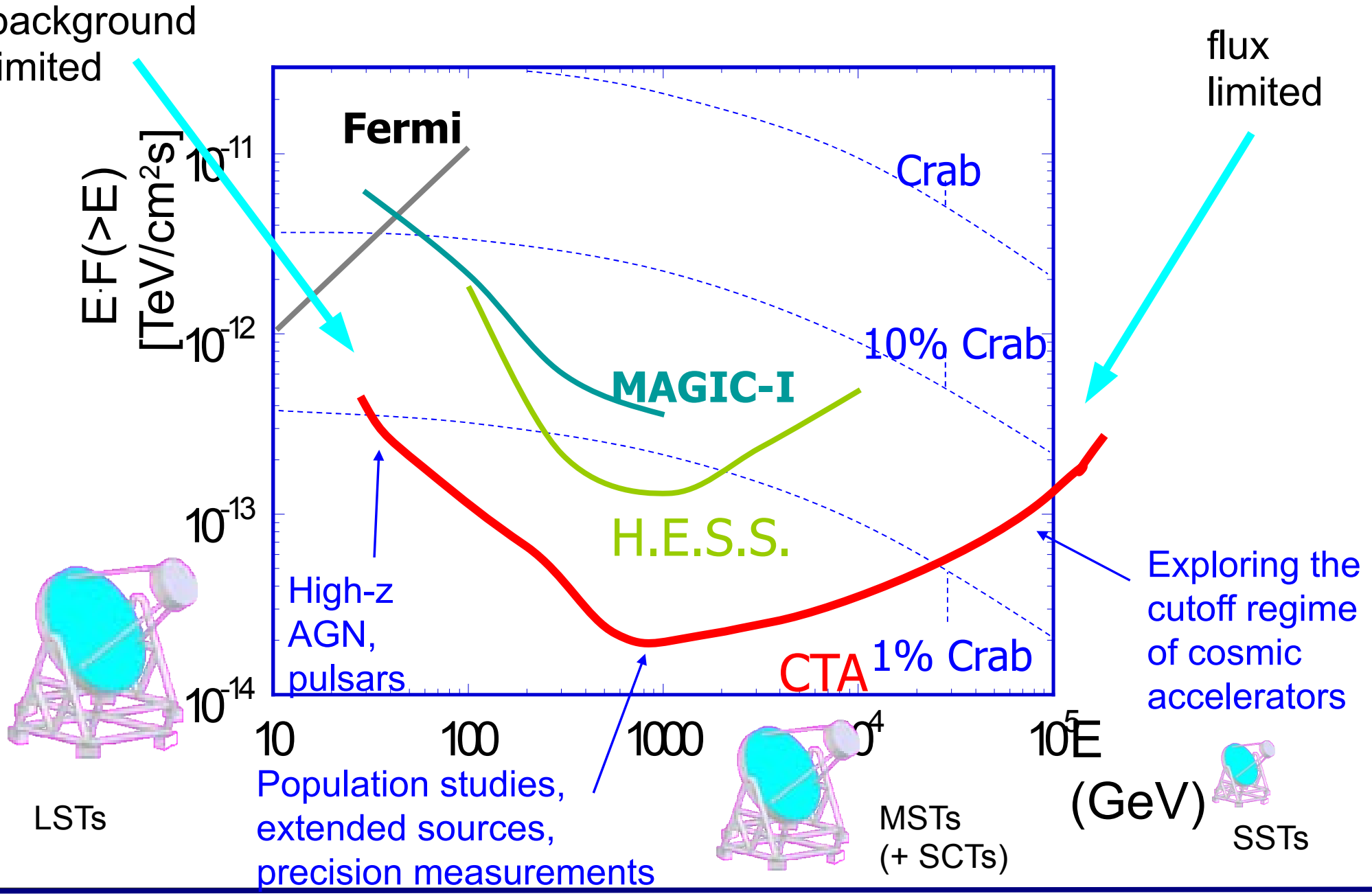


Figure from K. Bernlöhr

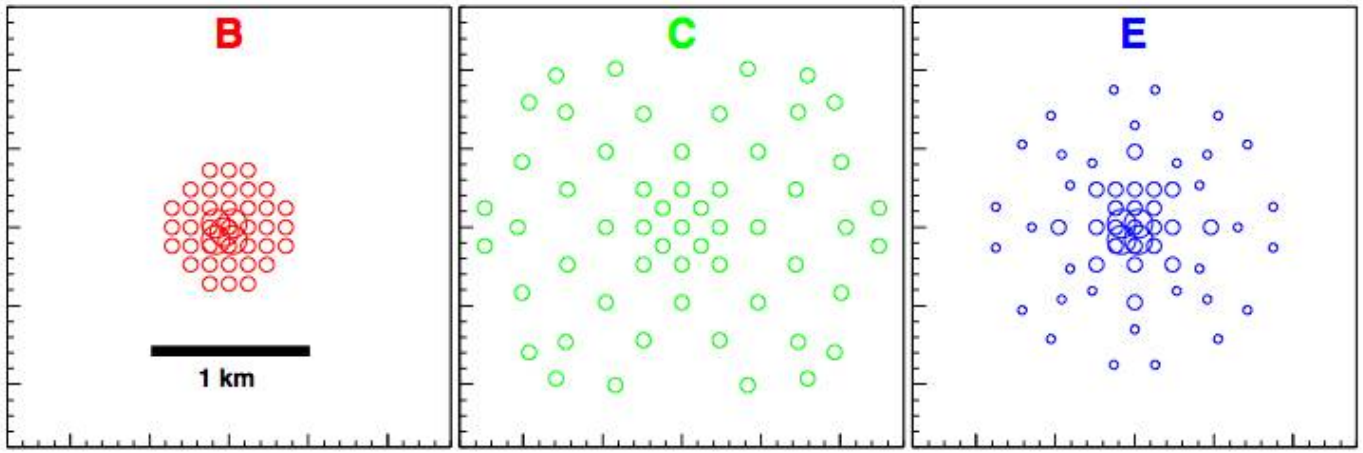
The primary goal of the US groups, CTA-US, is to enlarge baseline MST array of CTA by additional 36 telescopes and boost sensitivity and angular resolution of CTA Southern Array.

V. Vassiliev

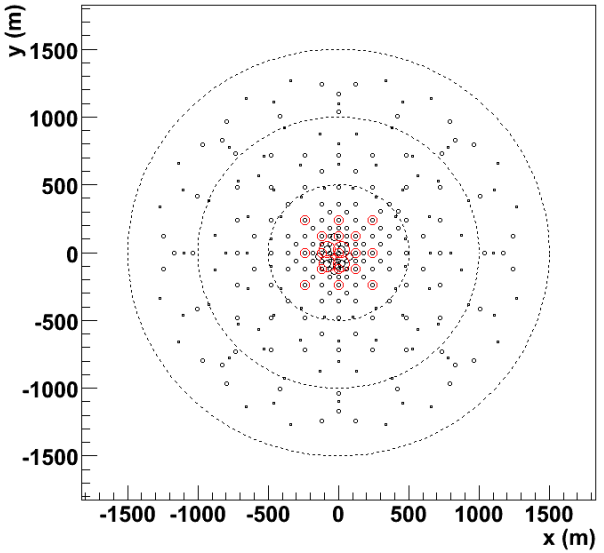
Goal for CTA sensitivity



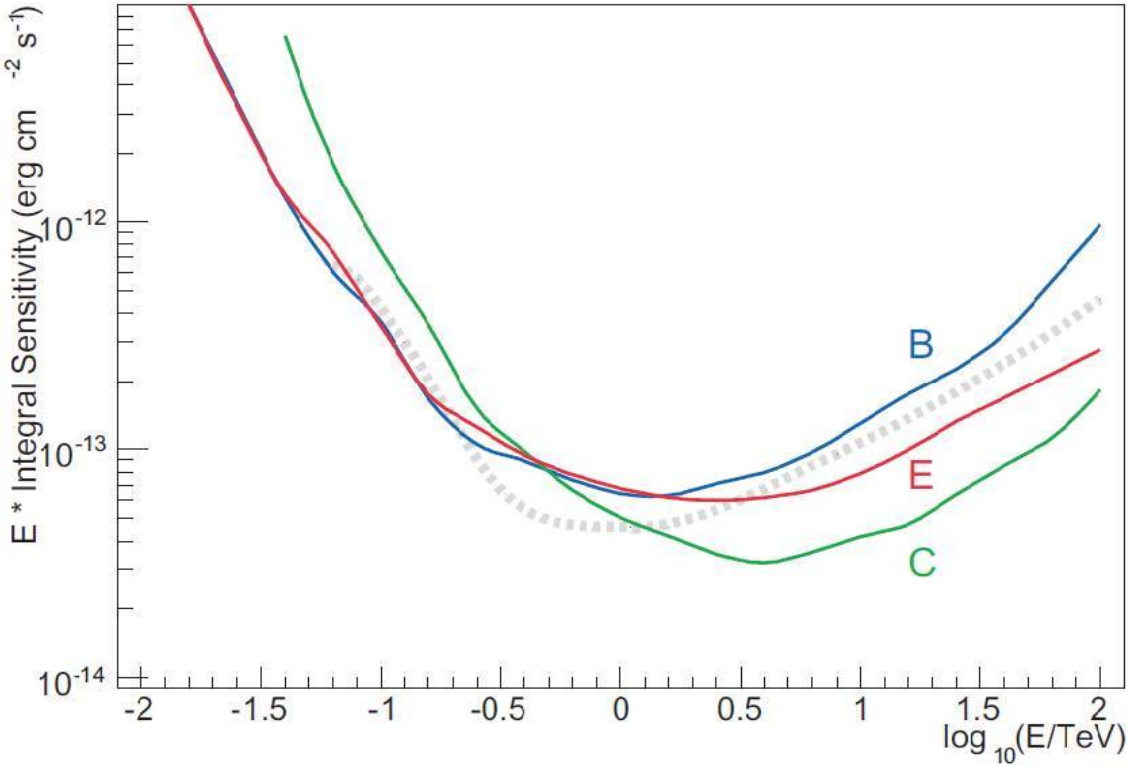
Simulations



examples for Southern Array (without SCTs)



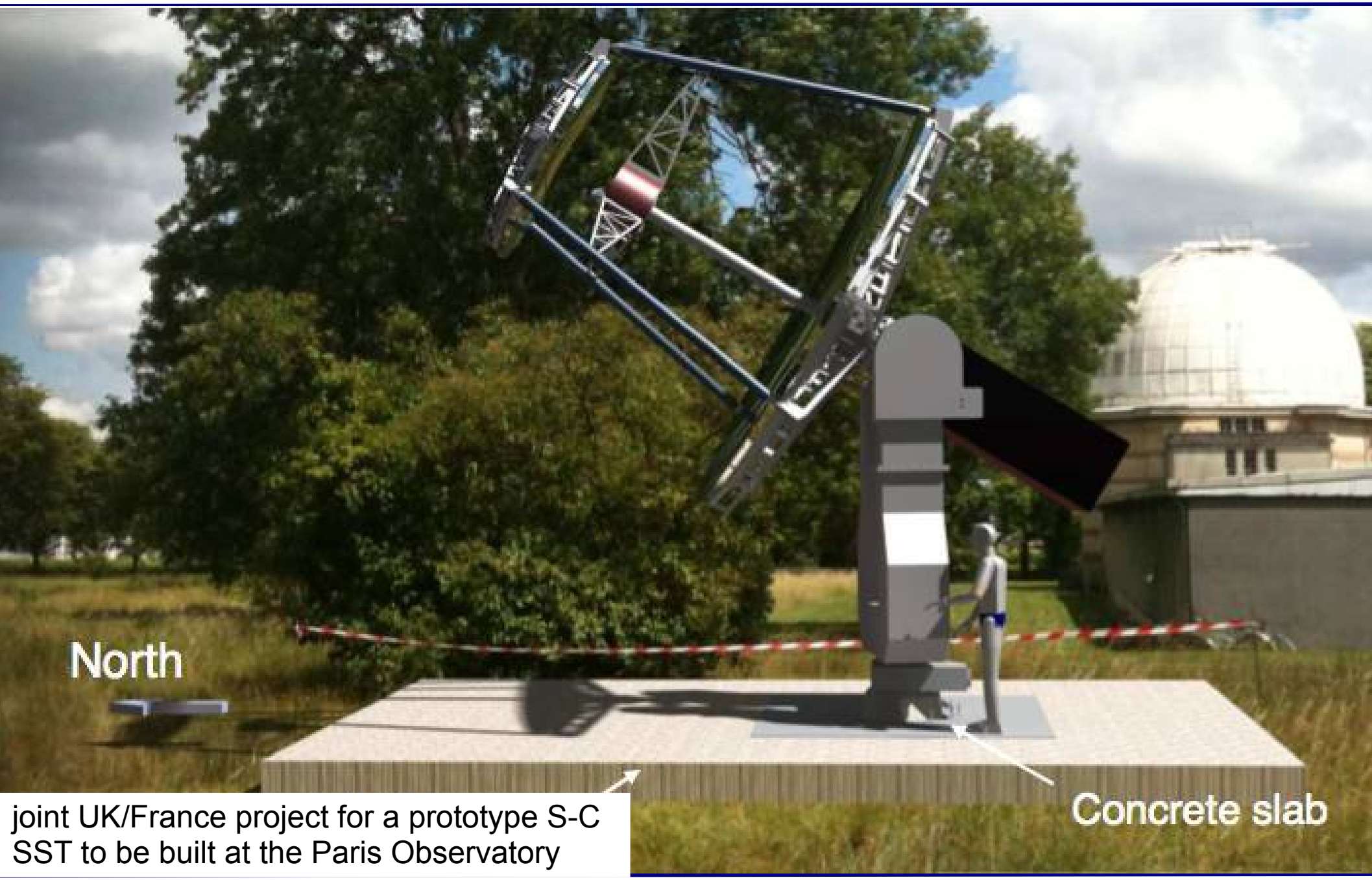
example for Northern Array (red circles)



current issues:

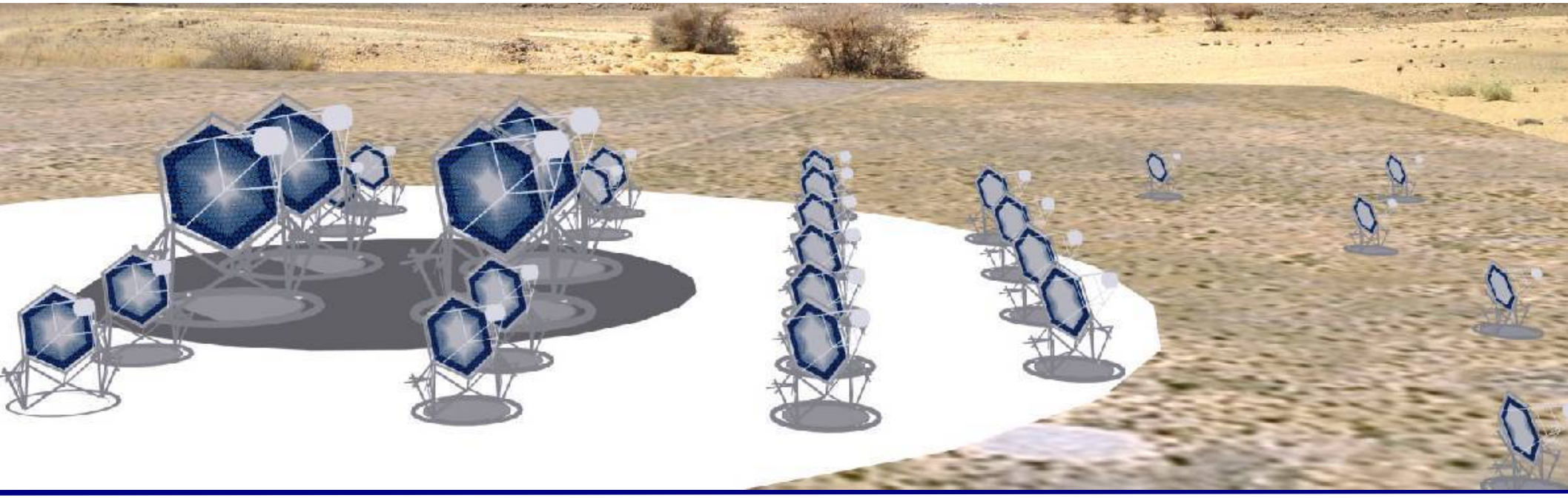
- trigger & electronics simulations
- S-C telescopes
- massive simulations on the GRID and on local clusters under way
- ...

SST-GATE: a S-C prototype



joint UK/France project for a prototype S-C SST to be built at the Paris Observatory

The AGN Science Case for CTA



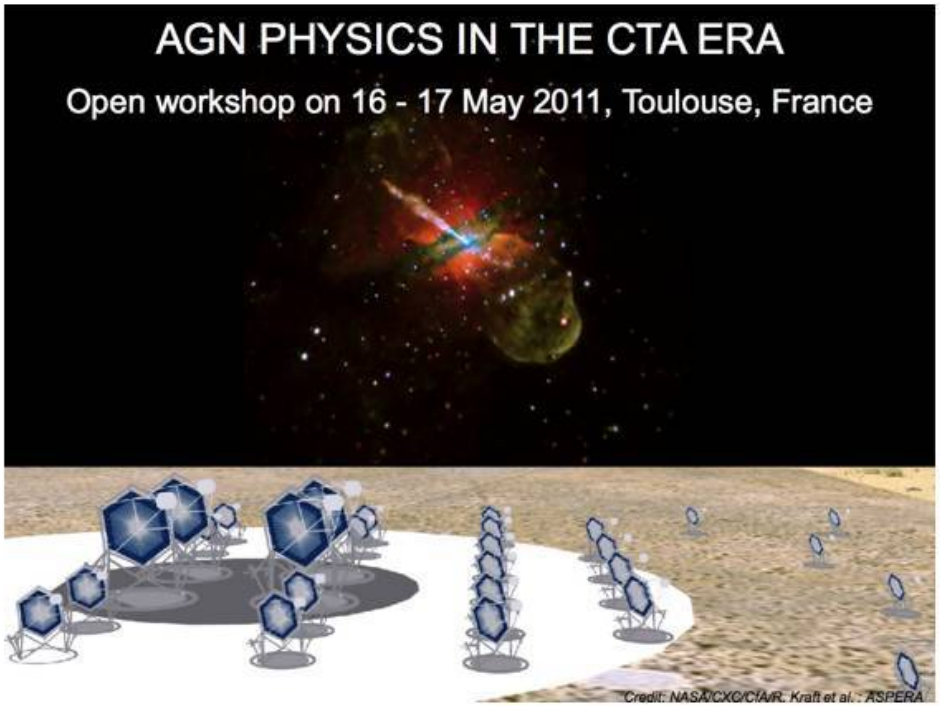
AGN workshop last May

cta-observatoire.fr

http://cta-observatoire.fr/agnworkshop2011

HOME | PROGRAMME & PRESENTATIONS | PROCEEDINGS | PARTICIPANTS | CONTACT

SOC:
M. Begelman,
C. Boisson,
G. Ghisellini,
H. Krawczynski,
M. Punch, H. Sol,
M. Totani, M. Urry,
R.Wagner, M. Ward,
A. Zech

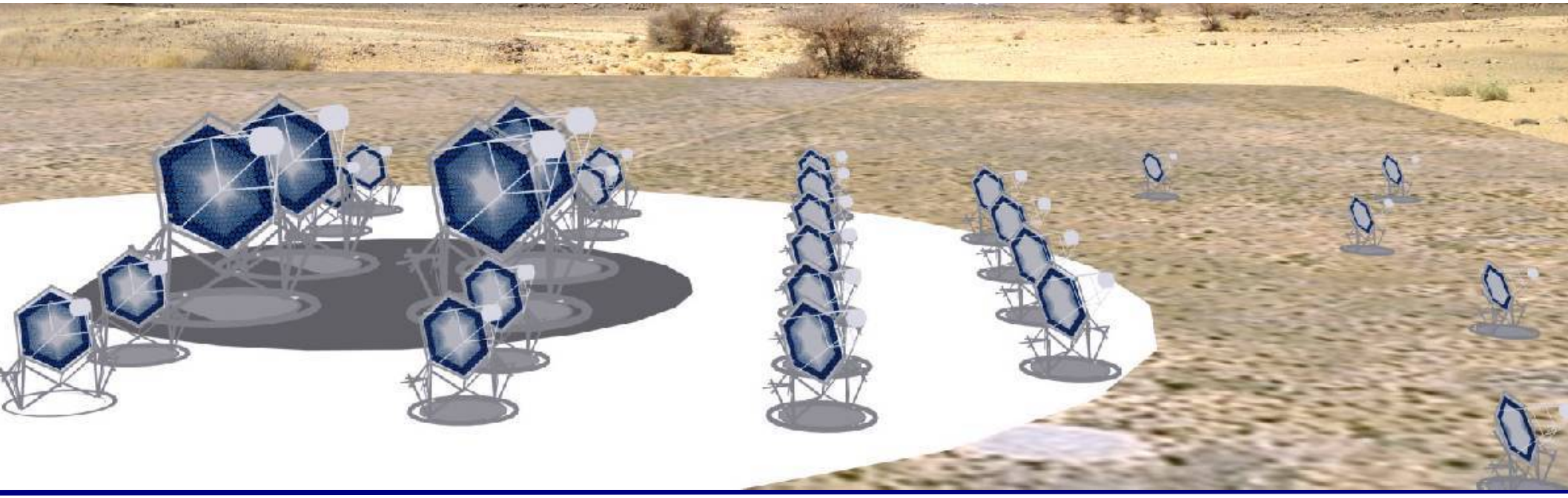


Proceedings to be published very soon !

With the start of its Preparatory Phase in 2010, a new step has been made towards the construction of CTA, the future large **Cherenkov Telescope Array** of ground-based gamma-ray astronomy.
A two-day workshop devoted to "AGN physics in the CTA era" was held in Toulouse, May 16th-17th 2011, in parallel with a **general meeting of the CTA consortium** . This workshop was open to all interested scientists.
Combining reviews and contributed talks, the meeting aimed at presenting the current state of the art and at characterizing future observing programmes for the various facets of AGN science at very high energies (VHE). Topics that were discussed included AGN population studies, particle acceleration and VHE emission models, variability studies, multiwavelength approach, blazar sequence and unification, connection with the EBL and intergalactic magnetic field ...

http://cta-observatoire.fr/agnworkshop2011

The AGN Science Case for CTA
Population Studies



Impact of CTA on population studies

The current VHE AGN sample is

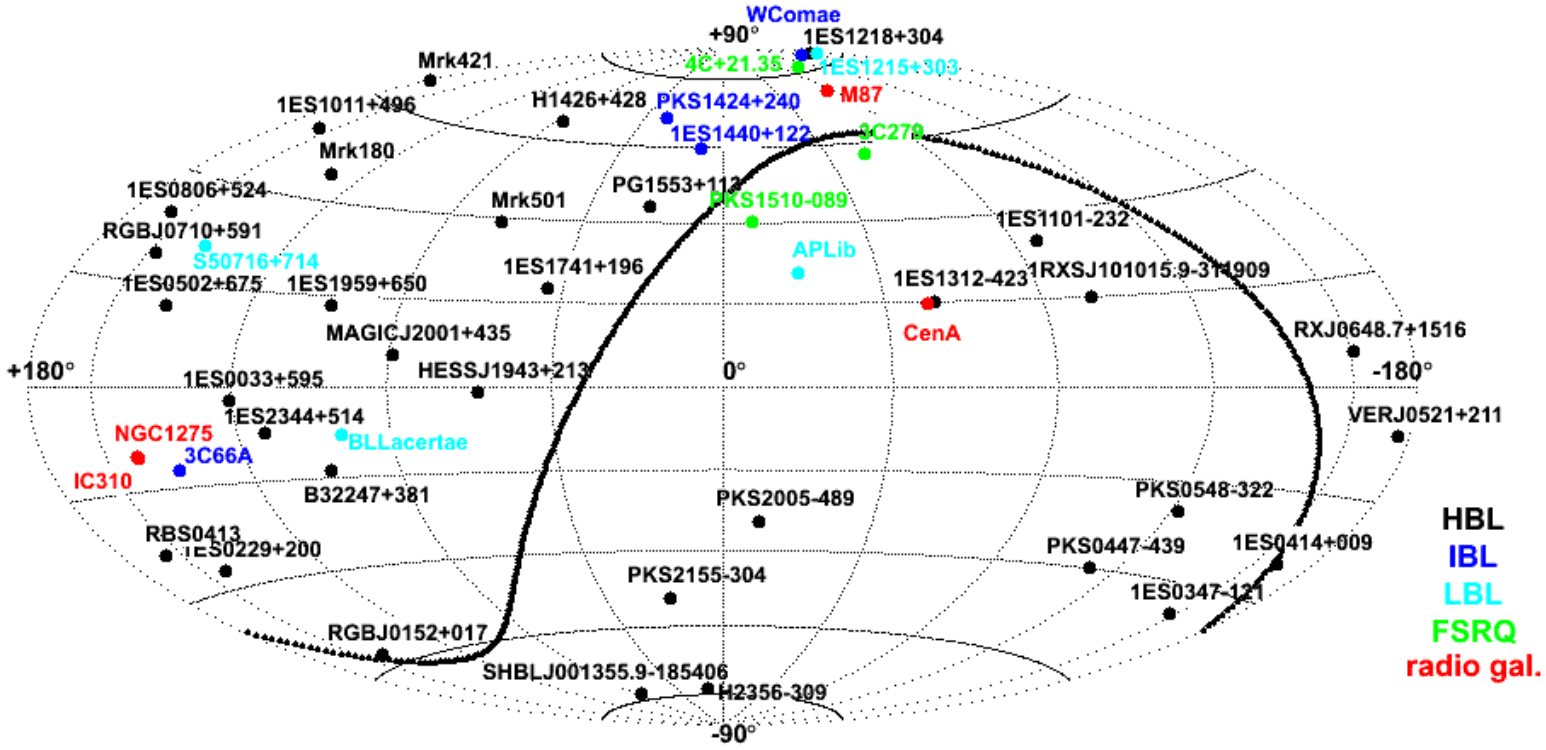
- very limited in statistics (especially for non BL Lac sources)
- highly biased towards strongly beamed, flaring and nearby sources

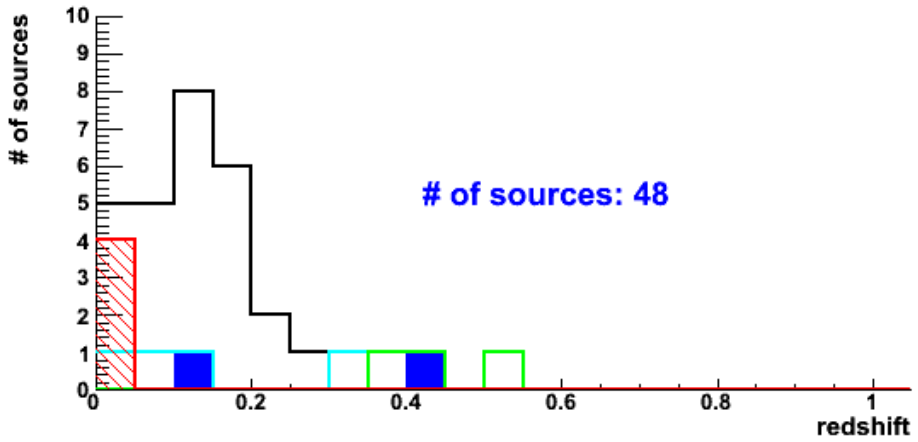
=> Difficult to

- derive a VHE luminosity function
- study unification models
- improve constraints on the EBL

CTA will help with these issues by increasing the **source statistics** and the number of **high redshift sources**.

The current VHE AGN sky

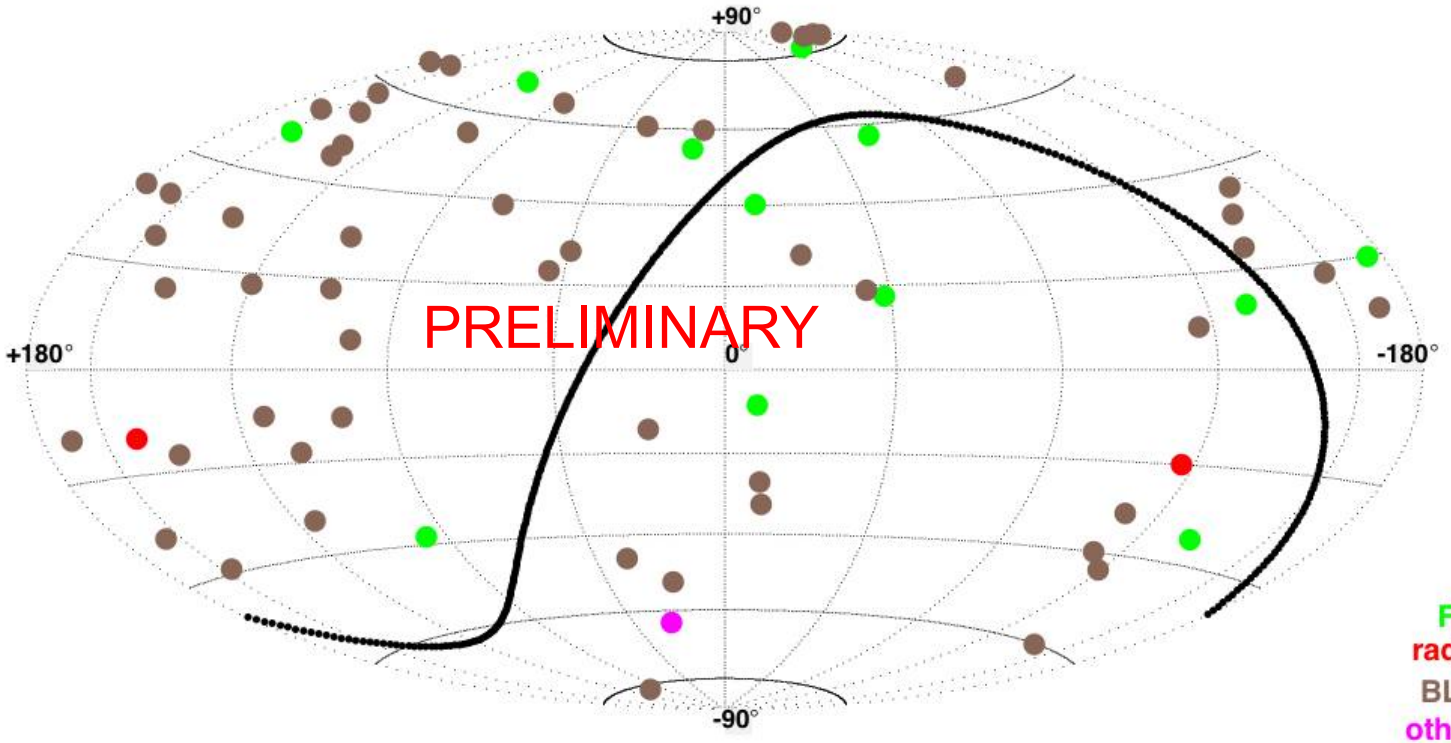




Fermi extrapolations

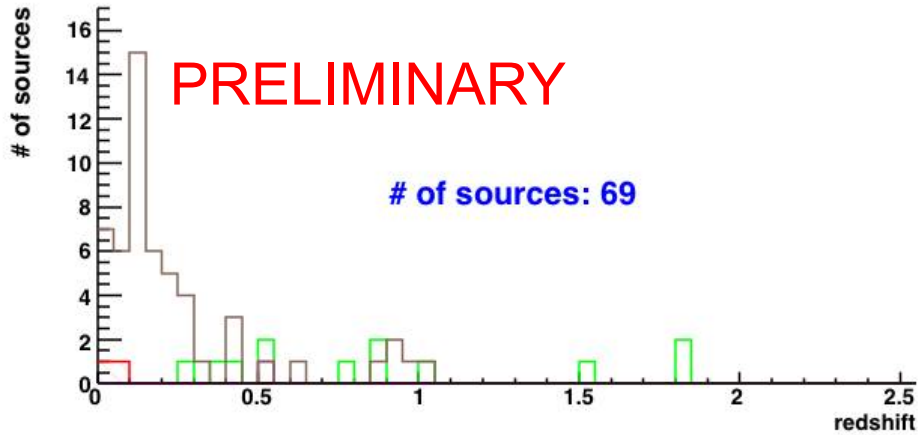
- Extrapolation of Fermi spectra (2FGL/Bzcat,Veron) to the TeV range (using PL or log parabolic form).
- "clean" sample, known z
- absorption on the EBL (*Franceschini et al., 2008*)
- Overestimates the # of detectable sources !
  - possible spectral breaks above Fermi band mostly ignored
  - all sources assumed at 20 deg zenith angle, configuration B
- Underestimates the # of detectable sources !
  - not all TeV blazars have been detected by Fermi ("only" 39 out of 45; only 34 in clean sample !)
  - does no account for flares or very active states
  - only sources with currently known redshift
  - additional SCT component not included in configuration B
- similar extrapolations have led to the discovery of new TeV sources (e.g. PKS0447-439, RGB J0648+152, ...)

Fermi extrapolations



- config. B
- max. 5h observation time per source

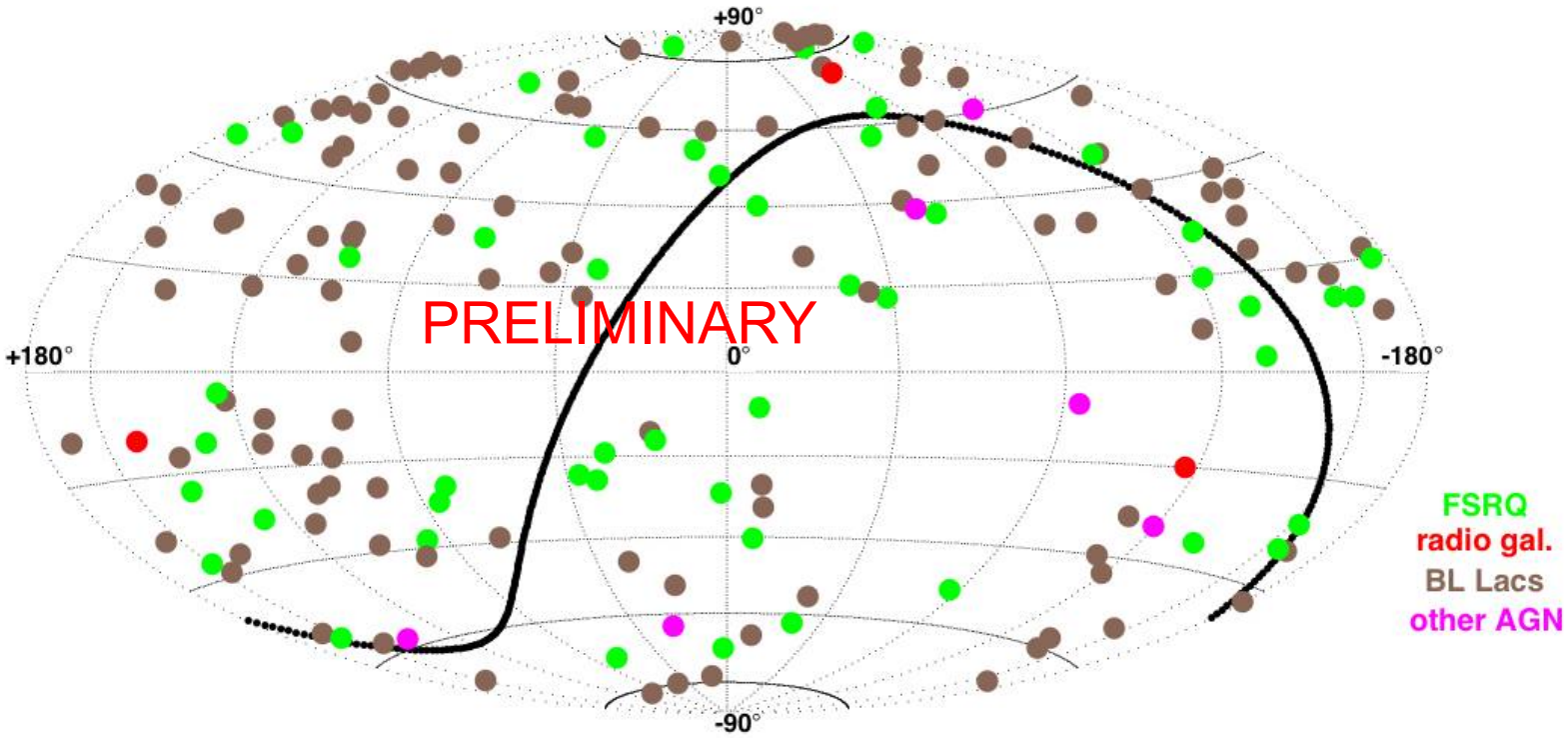
FSRQ
radio gal.
BL Lacs
other AGN

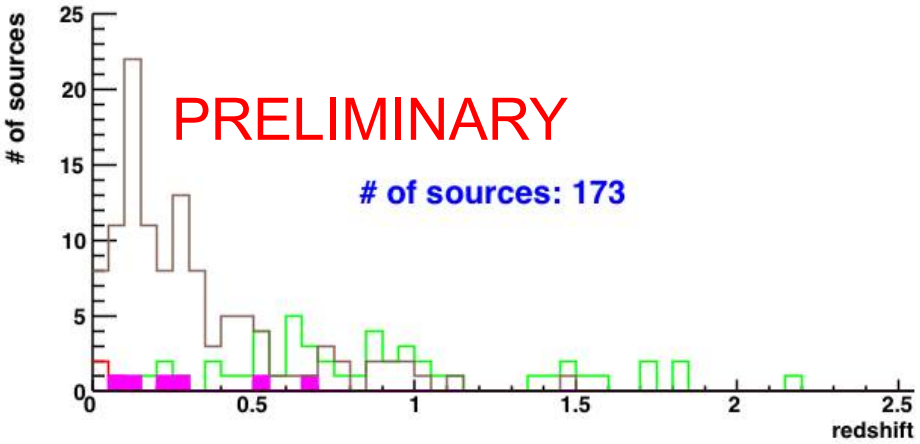


should be obtained in less than 2 months

Fermi extrapolations

- config. B
- max. 50h observation time per source

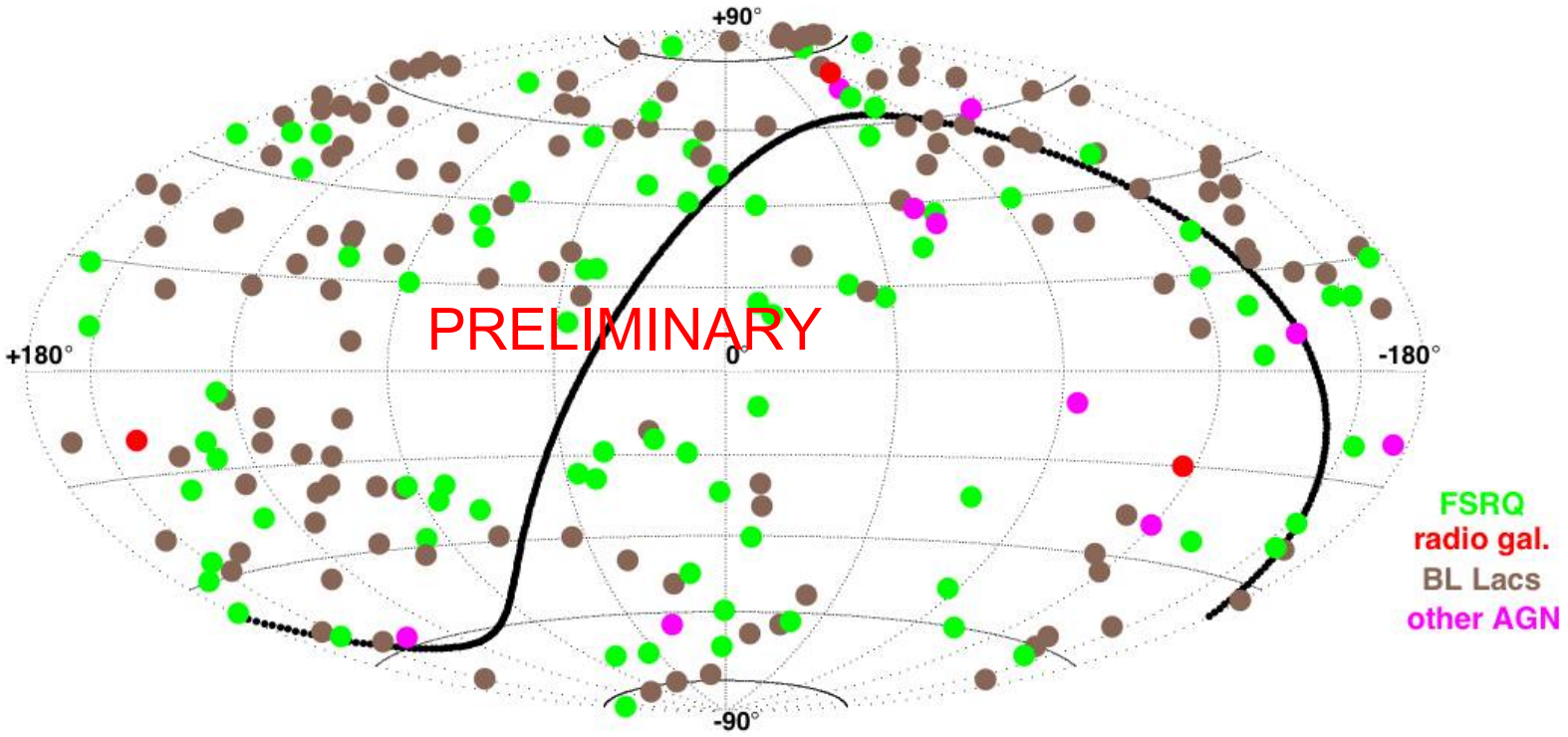


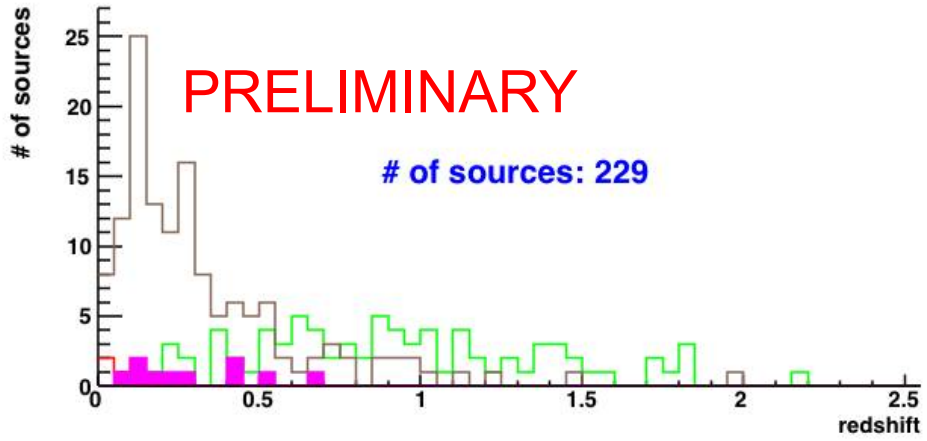


should be obtained in about 3 years

Fermi extrapolations

- config. B
- max. 150h observation time per source





should be obtained in less than 10 years

Blank Sky Surveys

Apart from targeted observations of Fermi AGN or radio/X-ray selected sources, blank sky surveys are considered for **unbiased** population studies.

For blank sky surveys, "**wide & shallow**" coverage is the fastest option to initially maximise number of sources:
full-sky survey: >50 sources for 1000 h (< 1 year)

With 50h/FoV, full-sky survey would take longer than expected life time of CTA of 30 years (-> ~370 sources)

Serendipitous discoveries are expected.

# of detections for a total of 100h of observation:

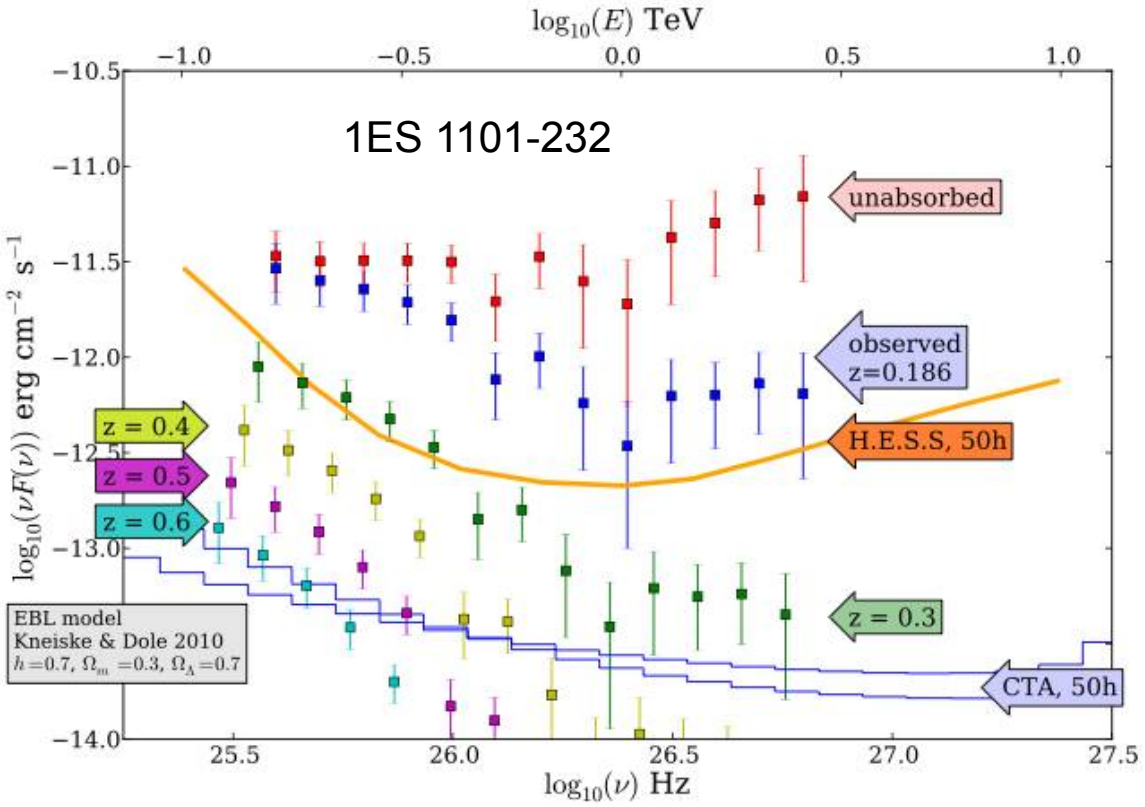
	narrow & deep ⟷ wide & shallow		
Config. I	40 deg^2 (50hr/FoV)	400 deg^2 (5hr/FoV)	4000 deg^2 (0.5hr/FoV)
>30 GeV	0.36	1.6	5.4
>100 GeV	0.35	1.5	5.2
>300 GeV	0.18	0.83	2.8
>1 TeV	0.06	0.25	0.9

Y.Inoue, T.Totani, AGN Physics in the CTA Era (FoV of 5 deg is assumed for CTA here)

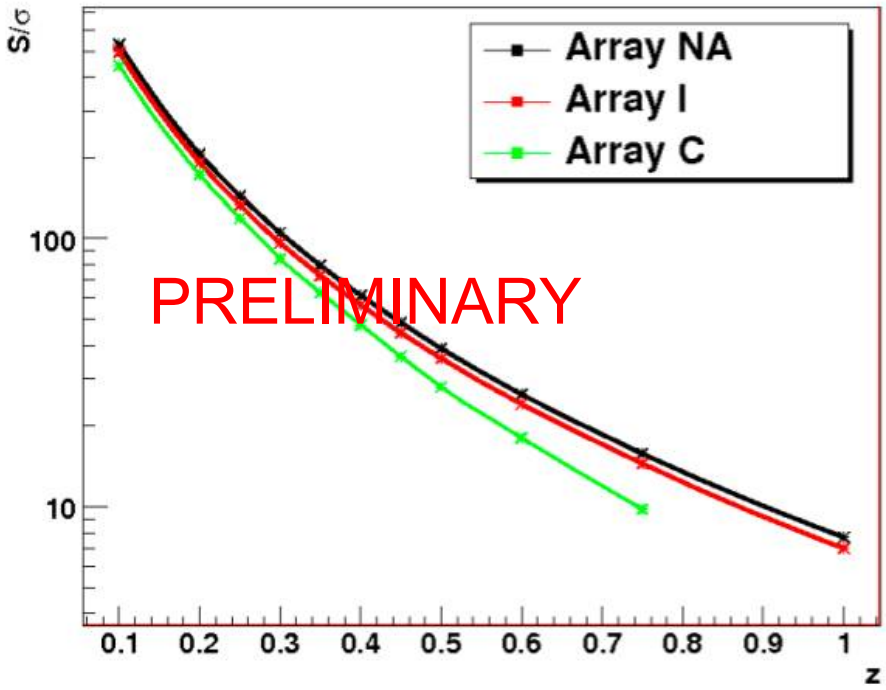
Blazars at high redshift

Blazars with hard spectra should be detectable up to very high redshifts with CTA.
-> interest for AGN evolution & EBL studies

Flares will help to access even higher z.



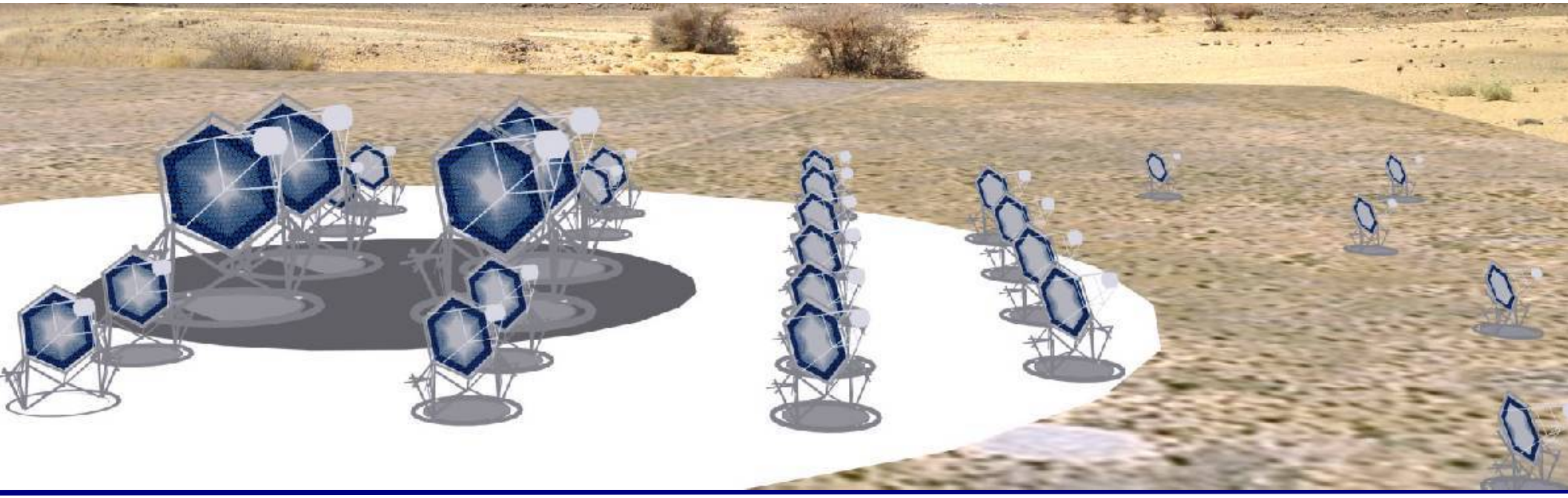
K. Katarzynski, AGN Physics in the CTA Era, 2011



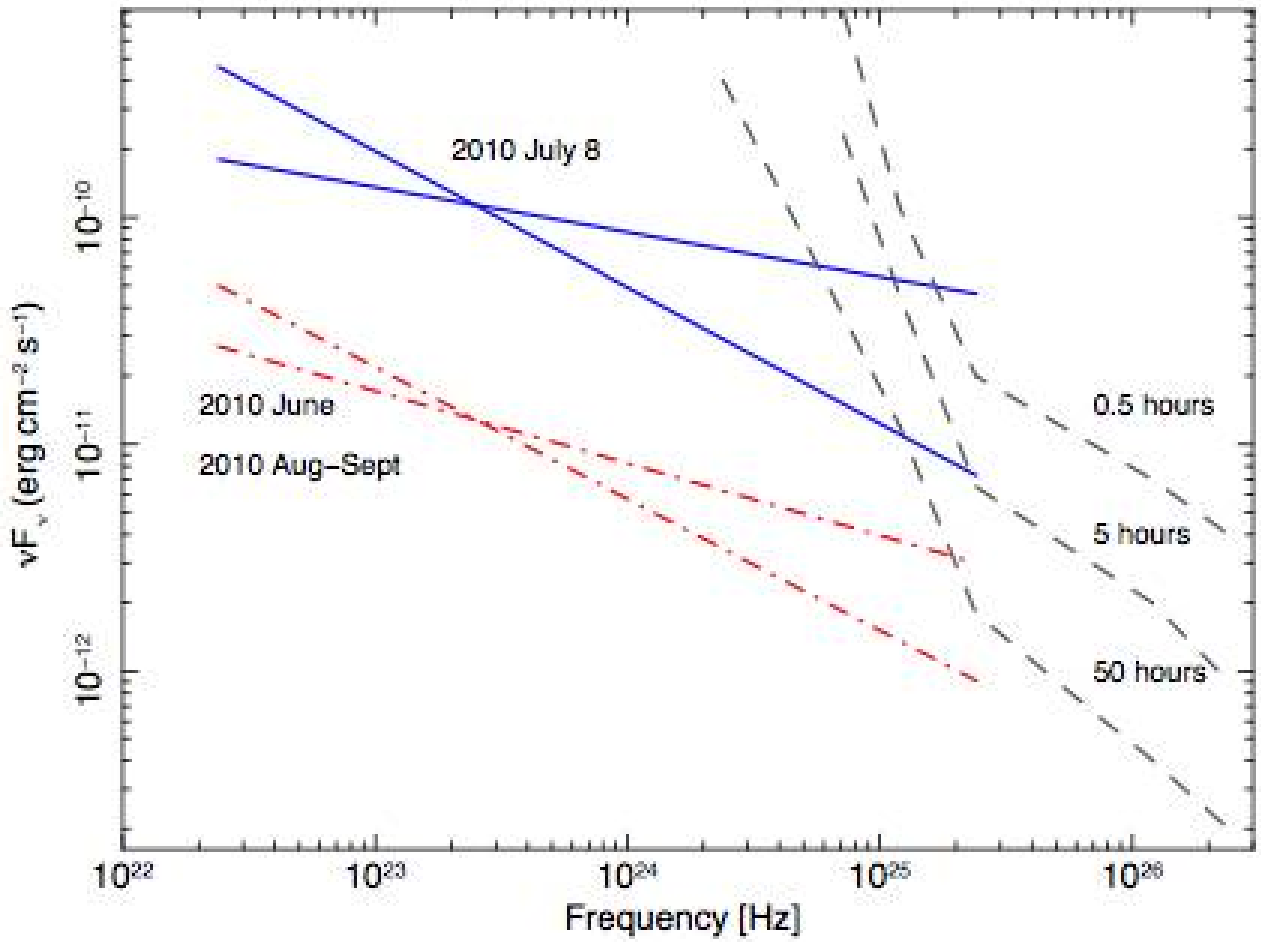
M. Cerruti (LUTH)

Expected signal of a strong flare (comparable to the 2006 flares from PKS 2155-304) for sources at different redshifts.

The AGN Science Case for CTA
New AGN Classes in VHE ?
Extended Emission ?



Narrow Line Seyfert 1



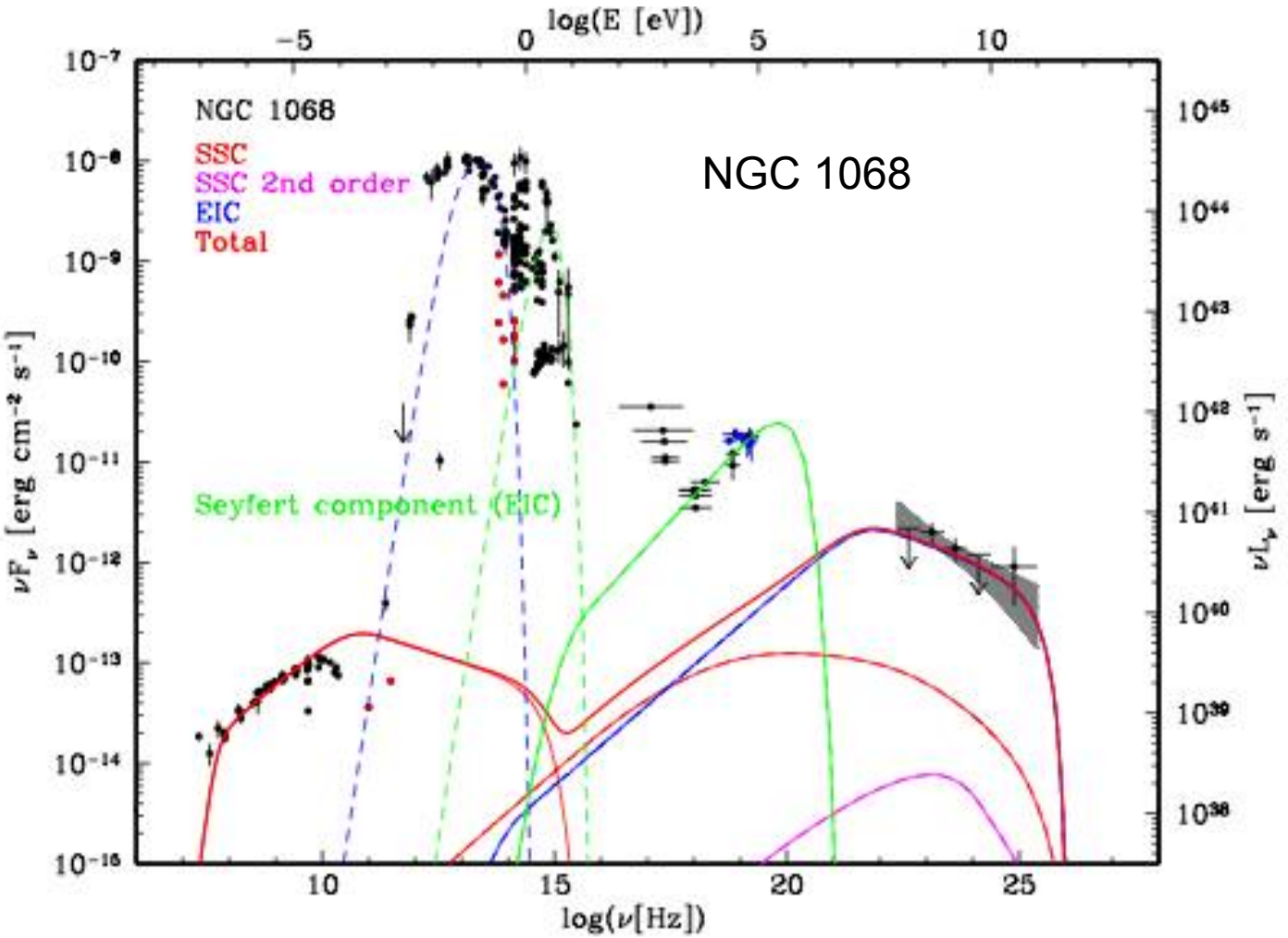
Foschini et al., astro-ph 1110.5649

Fermi detection of the NLS1 PMN J0948+0022 (and of other NLS1)

=> good perspectives for CTA, especially during flares

"*... it is now possible to study an unexplored range of black hole masses and accretion rates...*"

Seyfert 2 ?

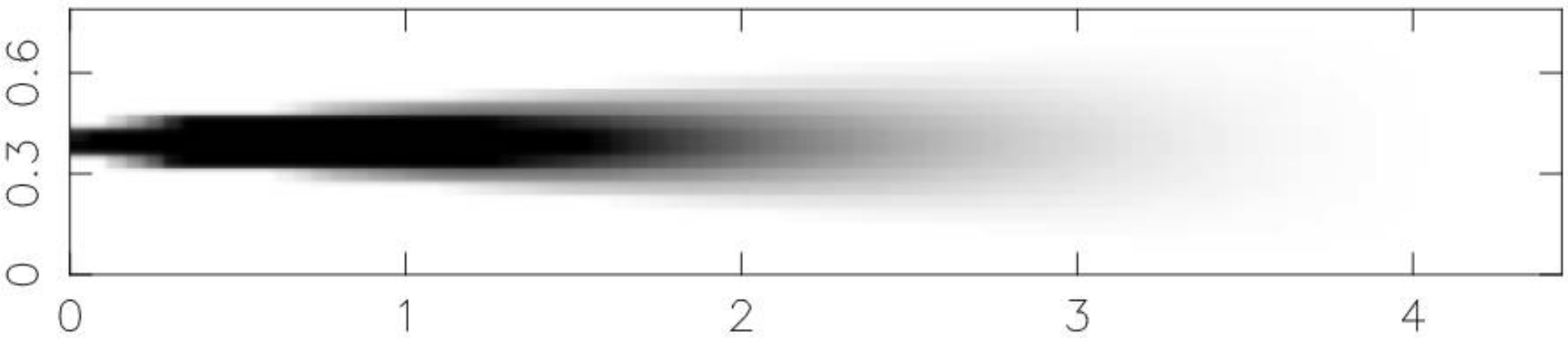


Lenain et al., A&A 524 (2010) 72

Suggestion of γ-ray emission from the Seyfert 2 galaxy NGC 1068, based on Fermi-LAT data.

=> could Seyfert 2s also be targets for CTA ?

Emission from extended jets ?



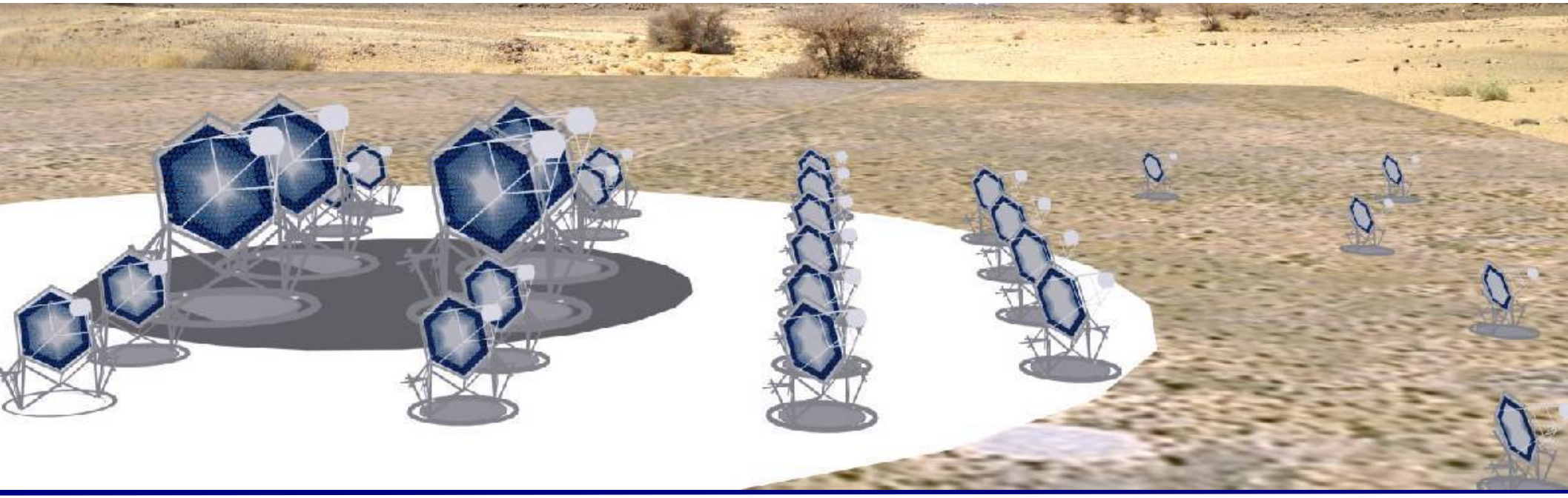
Hardcastle & Croston, MNRAS 415 (2011) 133

Centaurus A:

- X-ray jet extension ~ 4 arc minutes -> large enough to be resolved with CTA
- However, most emission is produced in central regions
- In an optimistic scenario, extended emission beyond 1 arc minute might be detectable
- A non-detection would place a very valuable lower limit on the magnetic field strength

Even if most jets cannot be resolved, possibility of distinguishing constant jet emission from variable component.

The AGN Science Case for CTA
Variability



Very rapid variability

e.g. 2006 flare of PKS 2155-304:

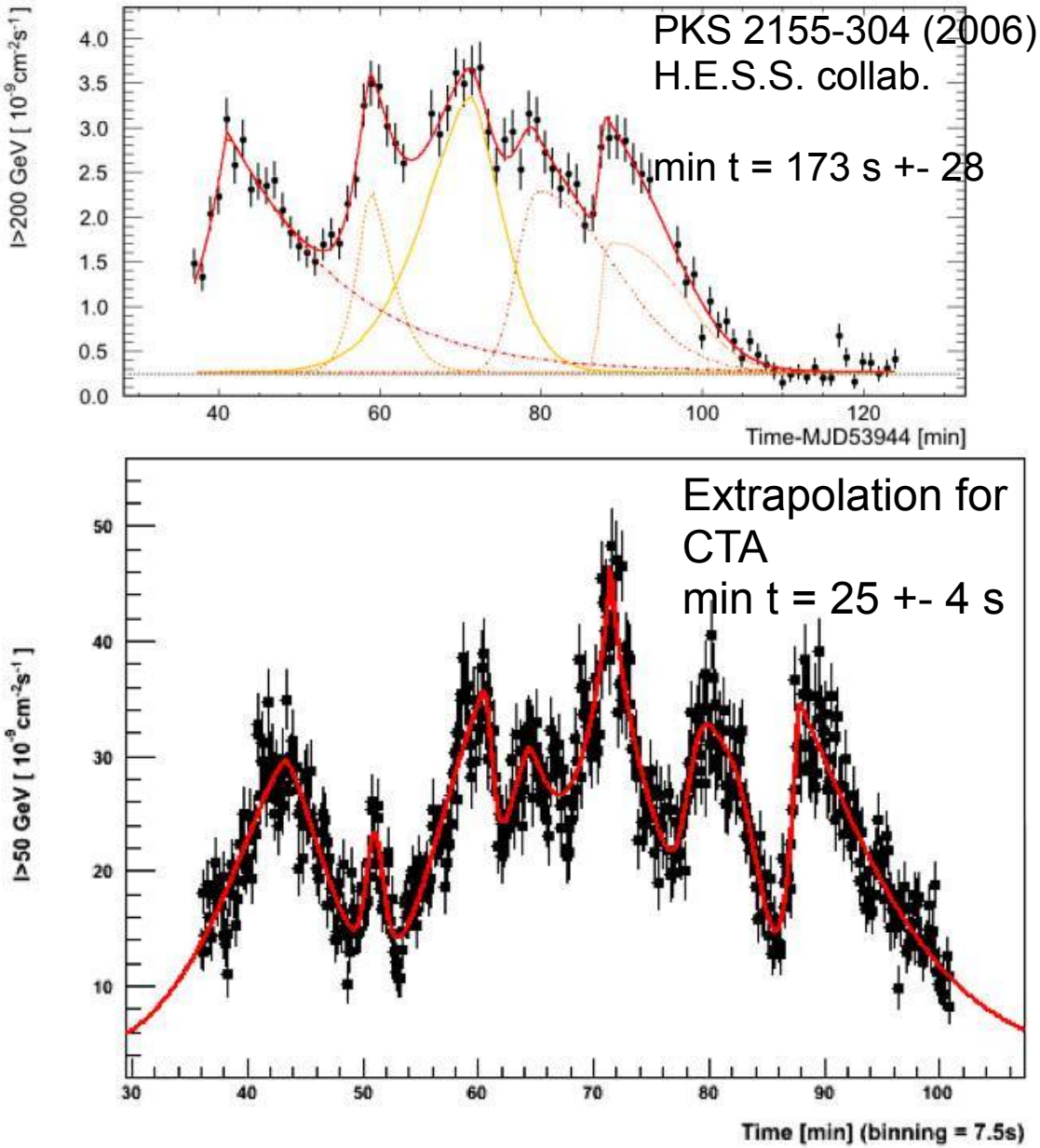
- H.E.S.S. detected > 100 γ-rays per minute
  => good statistics down to the 1 min. scale

  => strong constraints on the size of the emission region and the Doppler factor

- With CTA, the rate would be a factor of ~ 10 higher

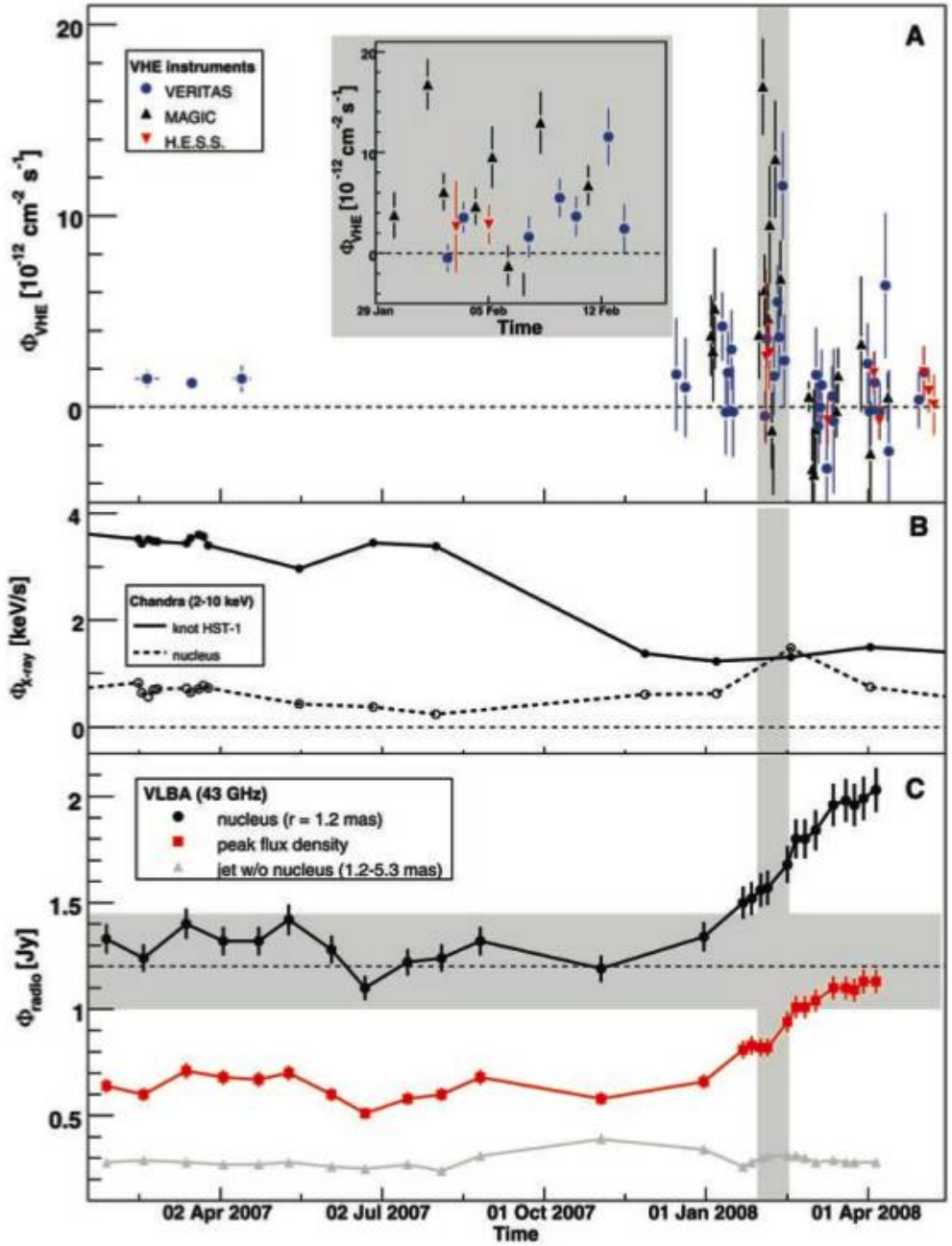
  => good statistics down to a few seconds (if power spectrum continues)

CTA will also allow us to test low states for the existence of rapid variability.



Biteau, Giebels, AGN Physics in the CTA era

The TeV / Jansky connection



M87 in 2008
(H.E.S.S., MAGIC, VERITAS, Chandra, VLBA)
- VHE variability on day-scale
- simultaneous X-ray flare from nucleus
- coincides with rise in radio flux from nucleus

=> TeV emission from inner jet or central core

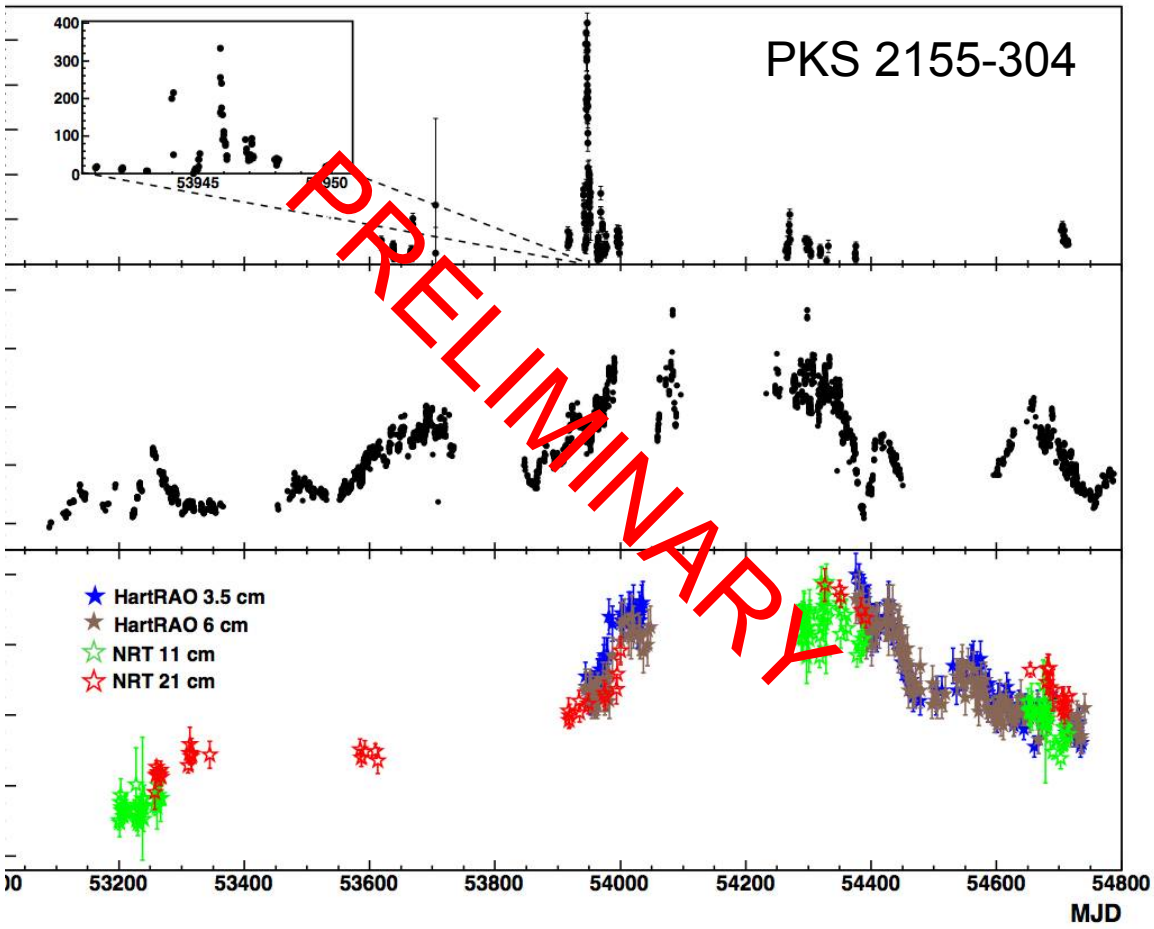
M87 in 2005
HST-1 favoured for TeV emission

M87 in 2010
- VHE flare with increased X-ray flux from core
- no increase in radio emission from core

=> long-term MWL observations needed to pin down the VHE emission region(s)
=> Synergy with HAWC and LHAASO (monitoring for flares)
=> Radio observations play a crucial role

Acciari et al., Science 2009

The TeV / Jansky connection



H.E.S.S. collab., submitted to A&A

PKS 2155-304

Very large flares in 2006 occur during a very active state in the optical and radio band.

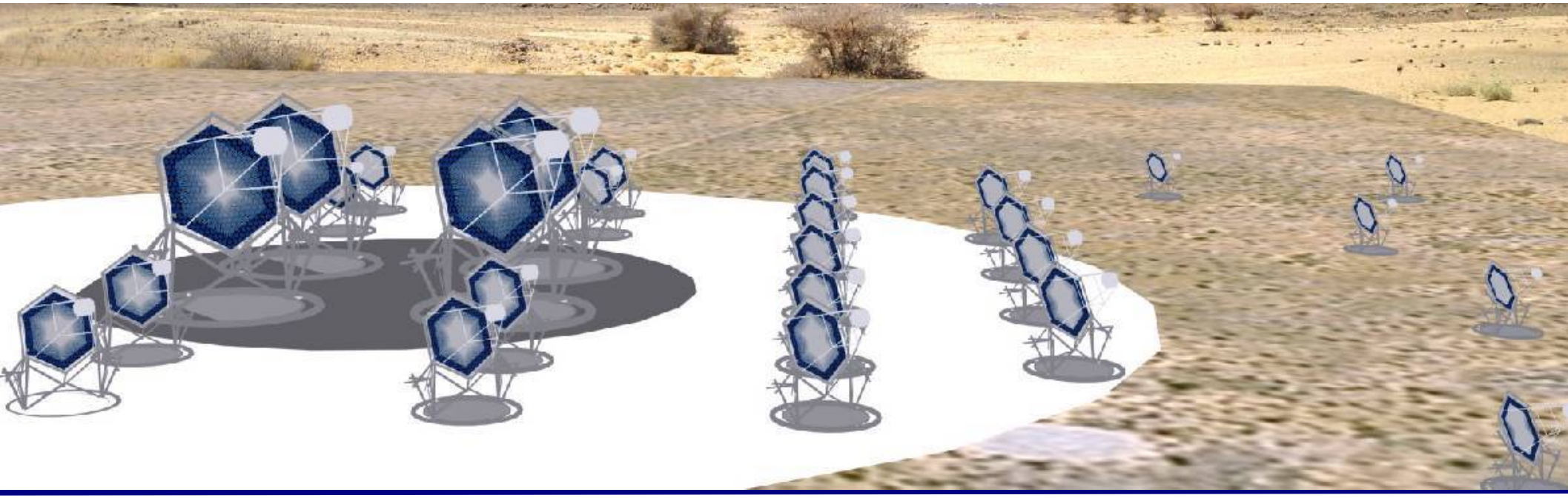
They are followed by a rise in the radio band in the long-term light curve.

Connection between lowest and highest energy emission in blazars ?

=> Need for coordinated long-term MWL campaigns (VHE data sparse !)

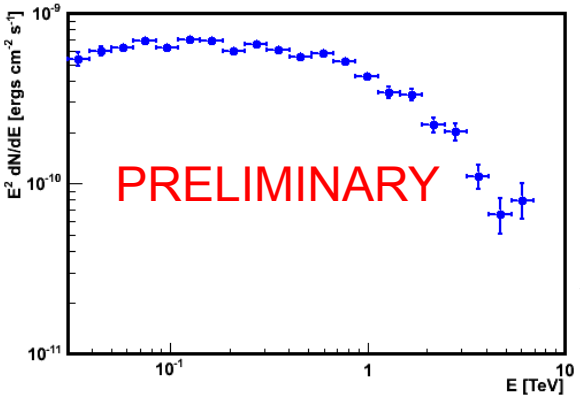
=> Need for more complete emission models that cover different time-scales

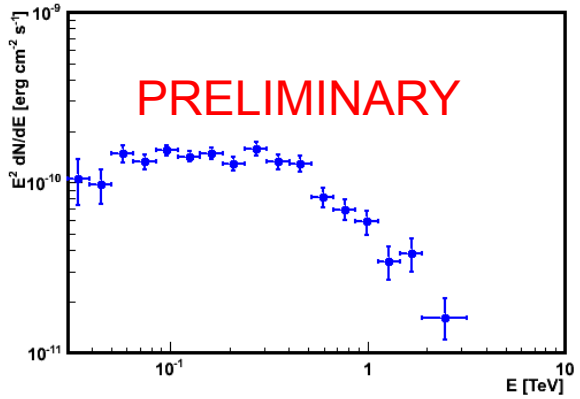
The AGN Science Case for CTA
Emission Models



Spectral evolution

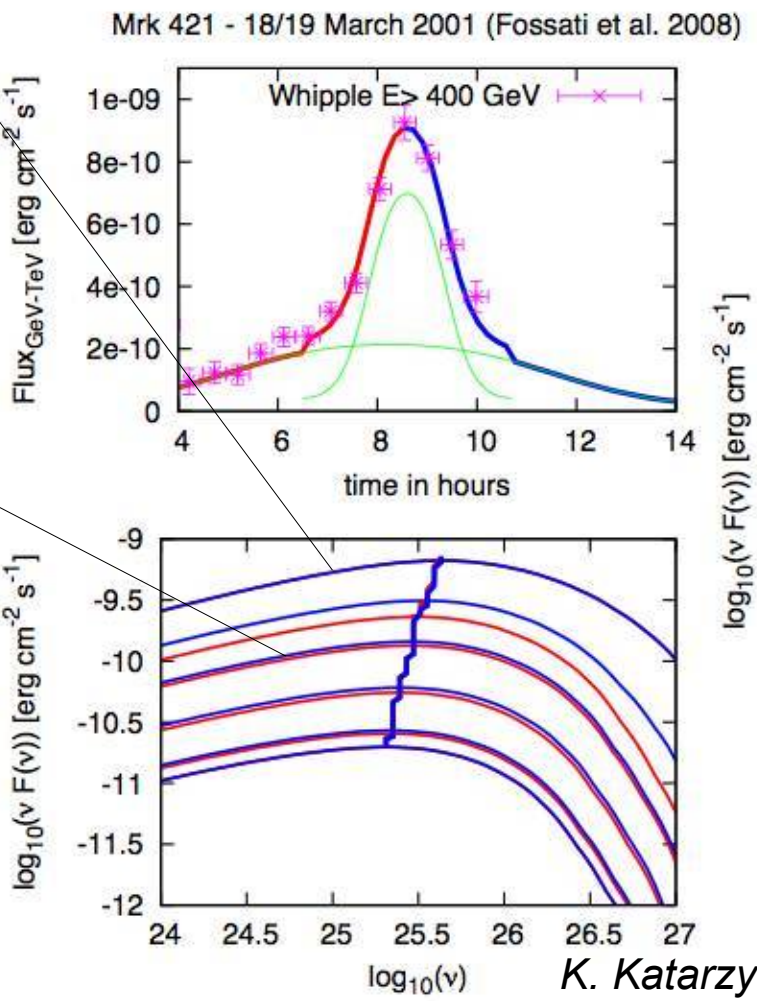
Spectral evolution during flares helps to distinguish different emission scenarios.
SSC scenarios: injection & cooling, acceleration & cooling, beaming...

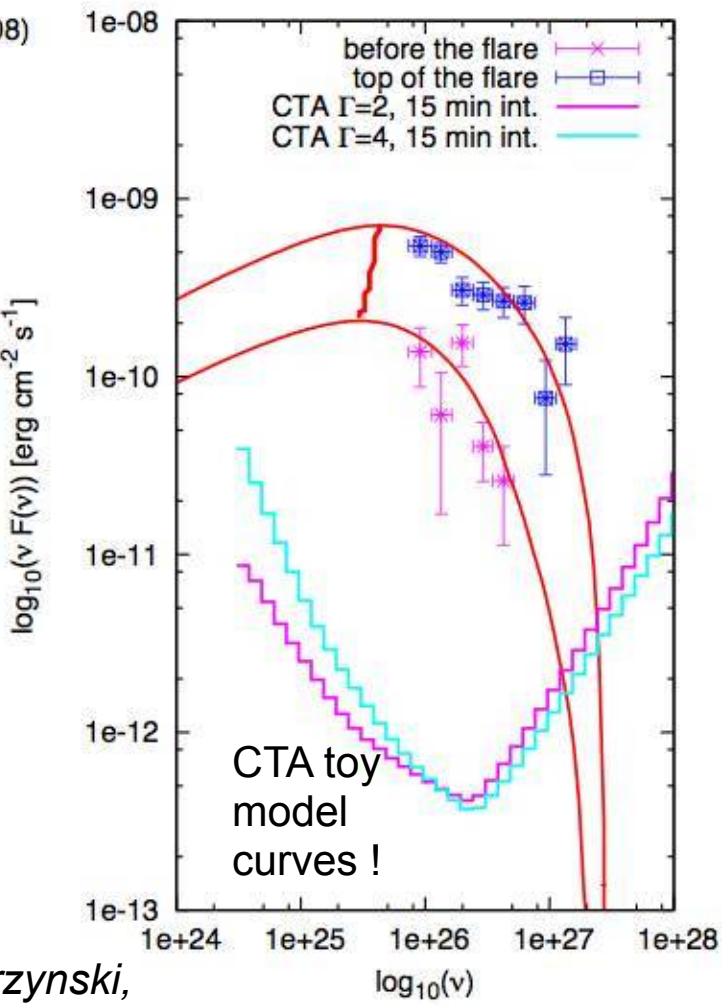




spectral evolution as seen with CTA (Δt=15 min.)

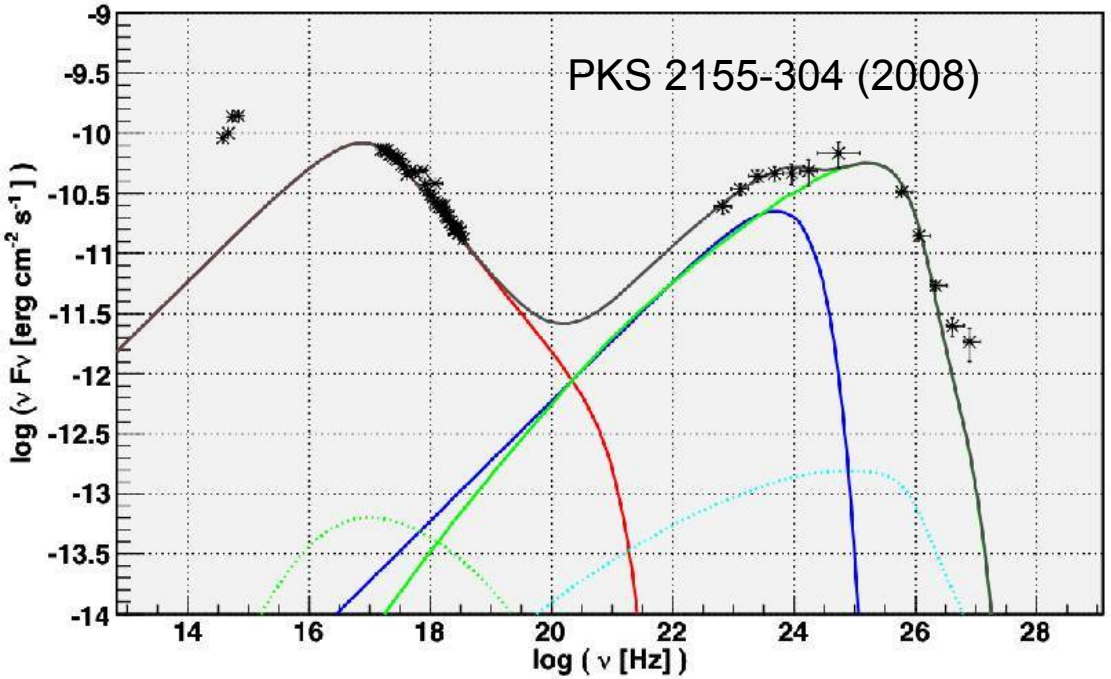
(simulation with scripts from D. Mazin)



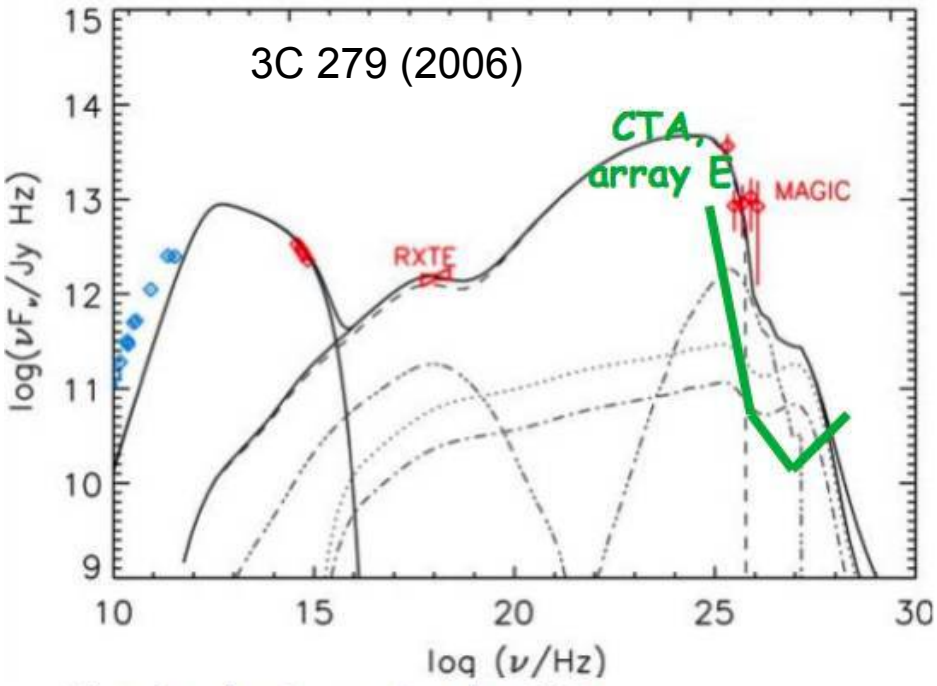


K. Katarzynski,
AGN Physics in the CTA Era

(Lepto-)hadronic models



M. Cerruti et al., astro-ph/1111.0557



[from: Böttcher, Reimer, Marscher 2009]

A. Reimer, AGN Physics in the CTA Era

Certain (lepto-)hadronic scenarios predict characteristic signatures in the HE/VHE band that could be tested with CTA. (in particular muon synchrotron + cascade, pion cascades)

-> connection with UHECR and astro-neutrino experiments (Auger, TA, ICECube, ANTARES...)

Absorption features

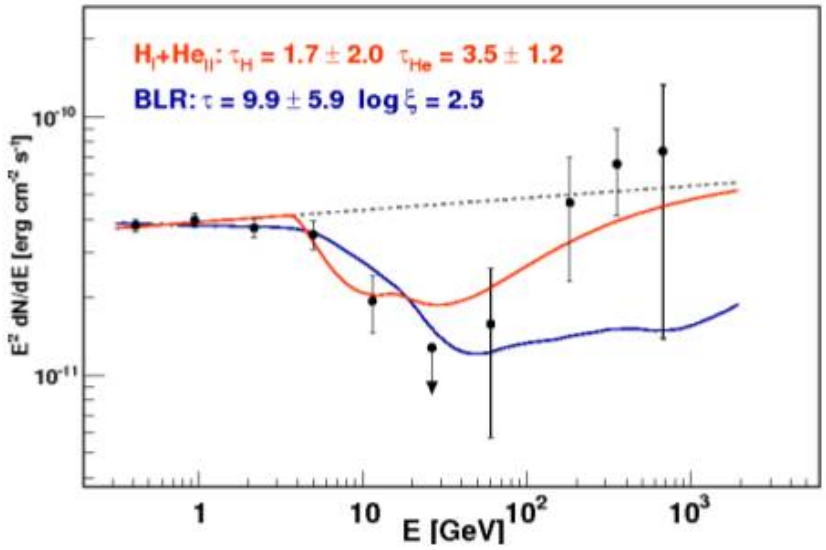
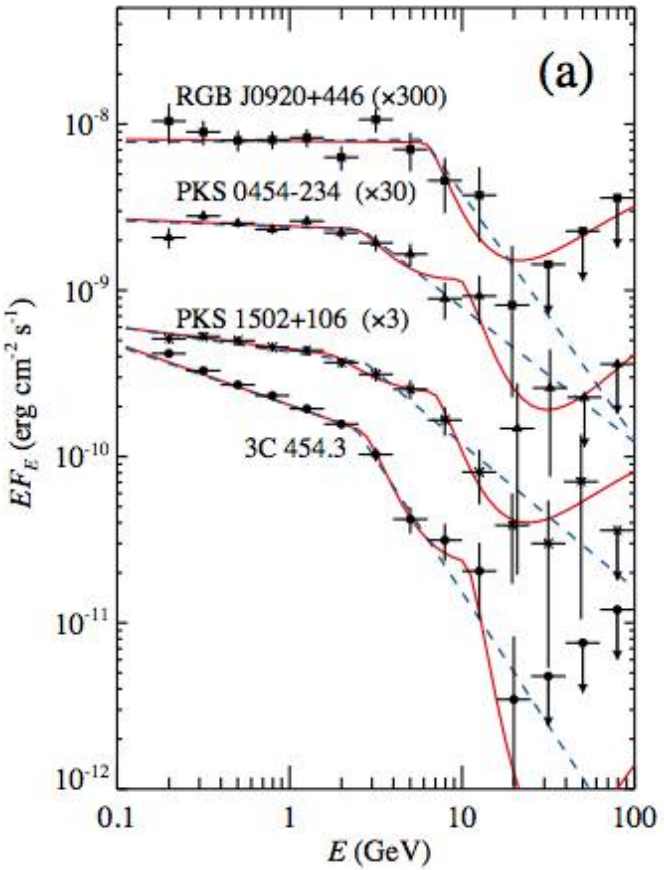


FIG. 4: *Fermi* high-state + MAGIC [23] spectrum for the LBL S5 0617+714. The red curve represents H I + He II absorption only and the blue one the full BLR absorption. The power-law fit is shown with the dashed line.

Sentürk et al., astro-ph/1111.0378



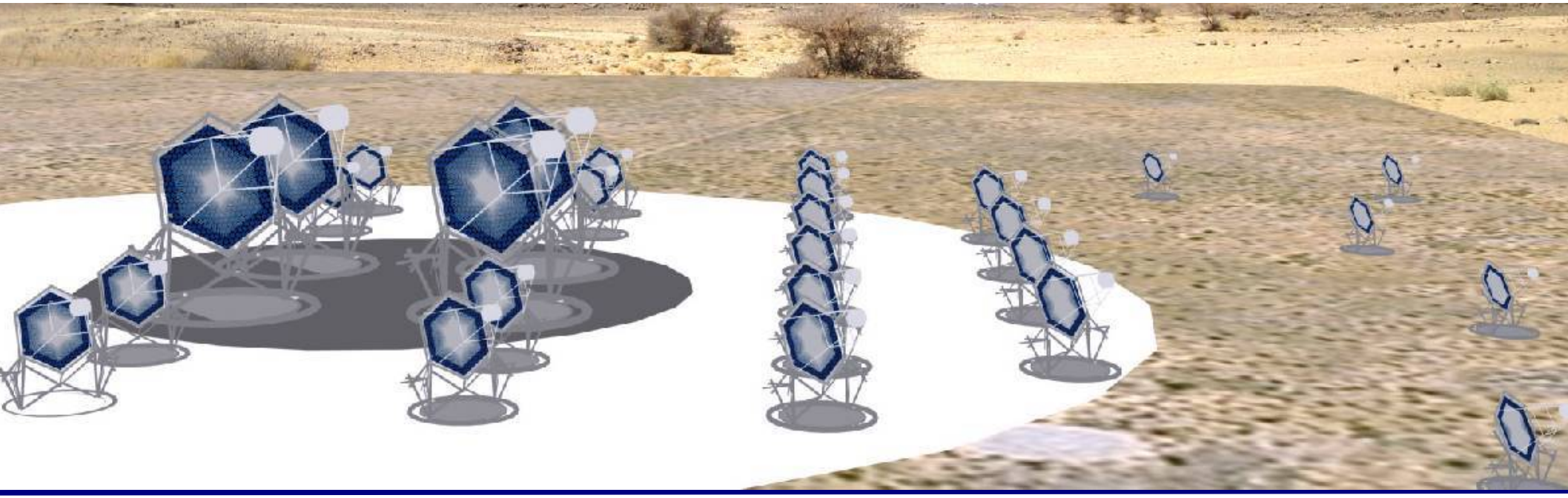
J. Poutanen, B. Stern, AGN Physics in the CTA Era, astro-ph/1109.0946

Some evidence for BLR absorption in Fermi (and VHE) spectra

-> absorption at a few 100 GeV by Balmer, Paschen lines ?

-> prospects for CTA
(low energy coverage, high sensitivity and energy resolution)

Conclusions



Conclusions

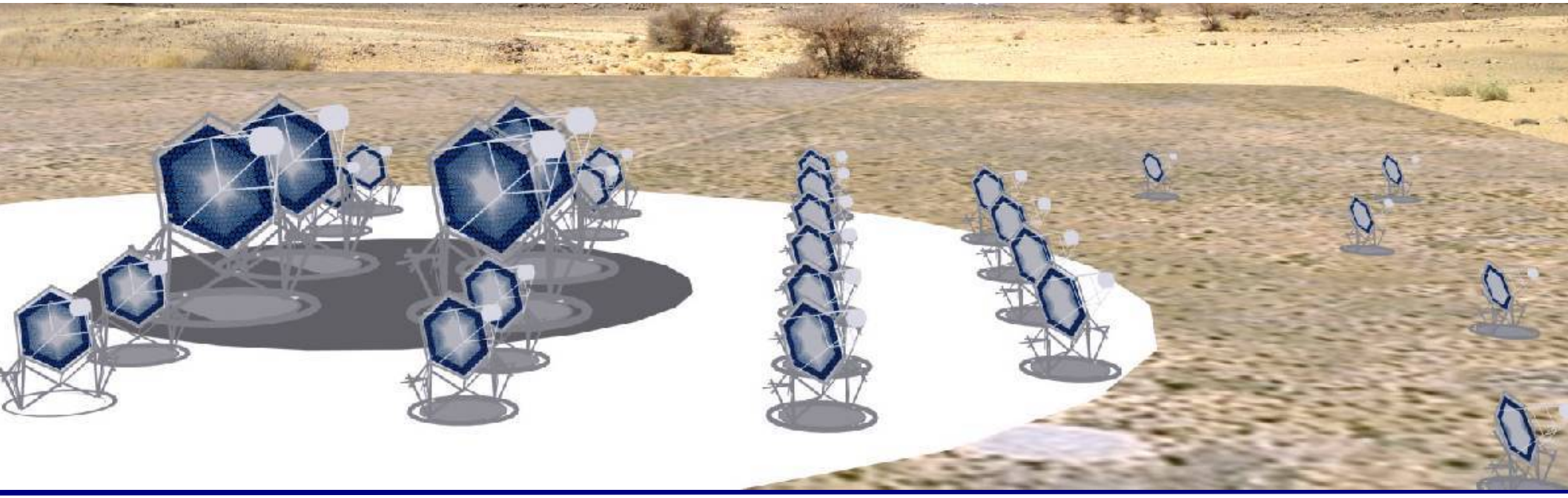
- CTA is in its Preparatory Phase, which is defining all technical details of the first open VHE observatory. Prototyping is under way.

- The impact of CTA on AGN physics will be (among others)
  - possibility of statistically meaningful population studies at VHE
  - variability studies down to the ~10 s scale with important consequences for our knowledge of the emission region
  - much stronger constraints on emission models
  - several methods to measure the EBL and put limits on the IGMF
  - guaranteed science return + potential to discover new types of VHE AGN

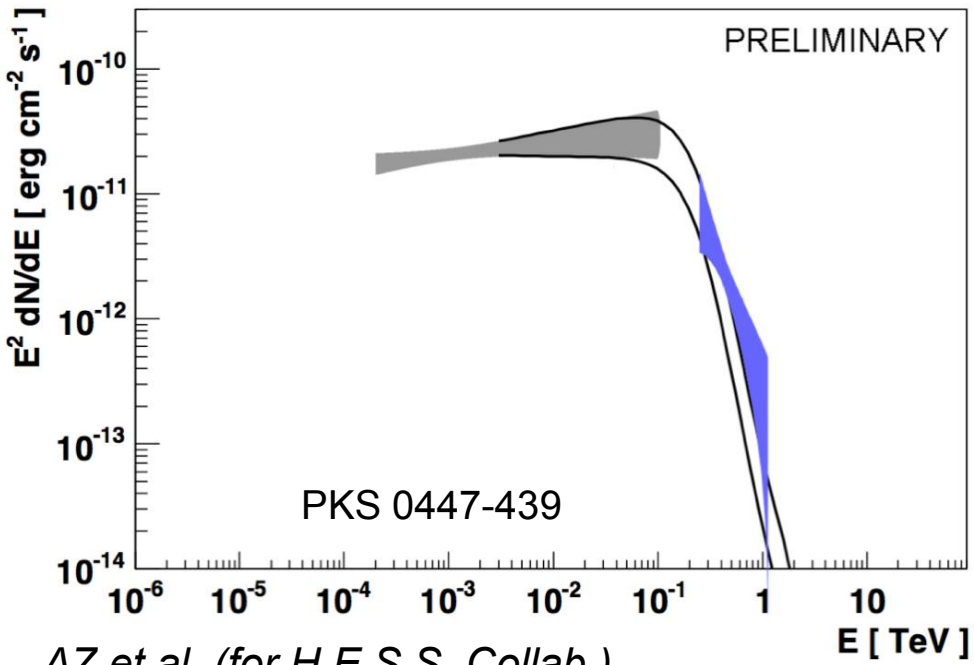
- Full potential of CTA will only be reached in multi-wavelength observations including other instruments over the whole spectrum + astroparticle telescopes

Backup Slides

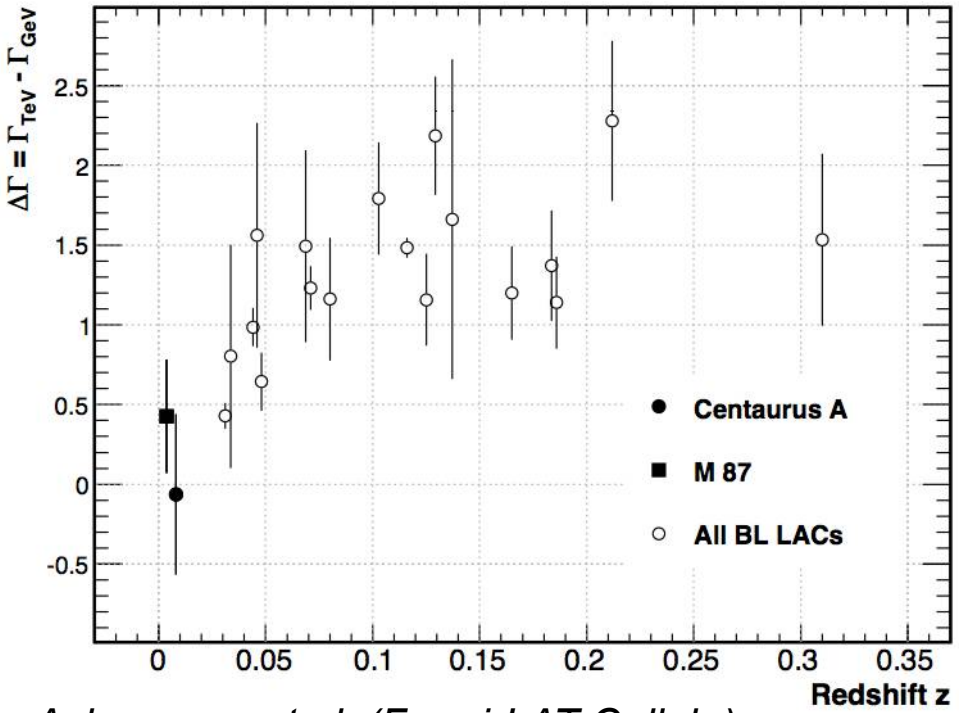
The AGN Science Case for CTA
EBL & IGMF



GeV-TeV constraints on the EBL



AZ et al. (for H.E.S.S. Collab.), astro-ph/1105.2548



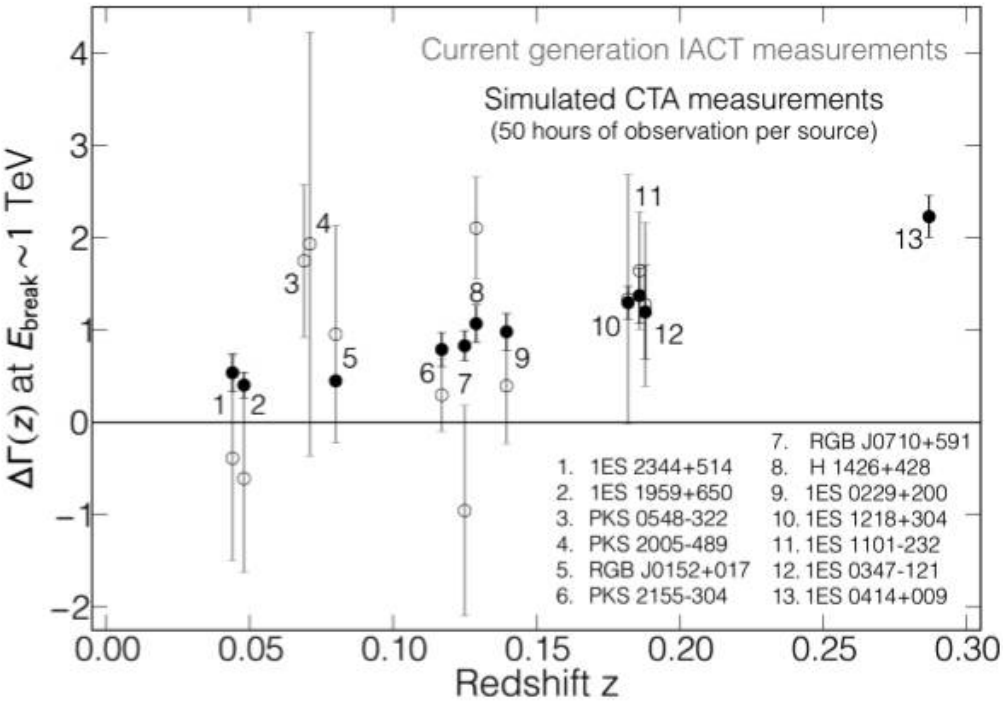
Ackermann et al. (Fermi-LAT Collab.), astro-ph/1108.1420

Spectral information from Fermi-LAT and Cherenkov telescopes used in two different ways:

- upper limit on the redshift of a blazar, based on a given EBL model
  -> important issue especially for BL Lacs
  -> need to reduce systematics between EBL models

- model-independent upper limit on the absorption by the EBL
  -> need to improve stastistics in VHE spectra & number of Fermi/VHE AGN

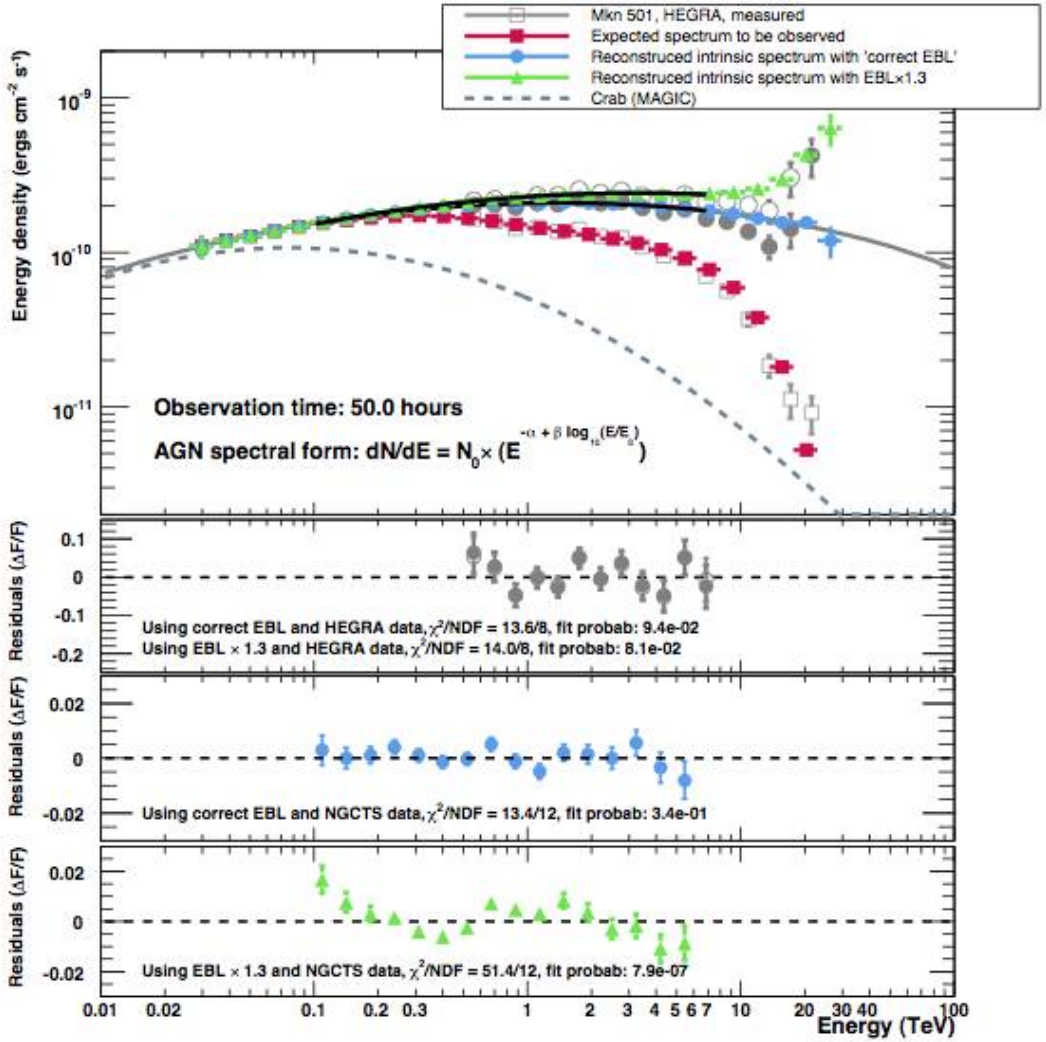
EBL imprint in VHE spectra



Orr, Krennrich (for CTA), ICRC 2011

Some EBL models predict spectral breaks around ~ 1TeV in the VHE spectrum.

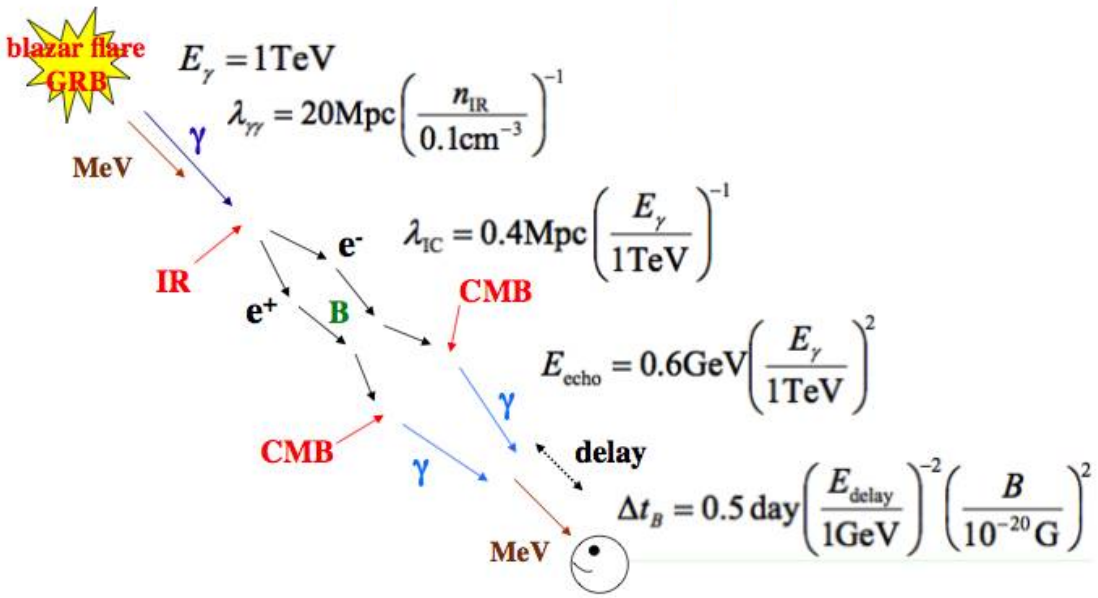
CTA should permit to decide if these breaks exist (simulations: filled points).



Mazin, Raue, Astroparticle Ph. 34 (2010), 245

EBL absorption varies with energy, leaves characteristic imprint in the VHE spectrum.

IGMF and pair echos



S. Inoue, AGN Physics in the CTA Era

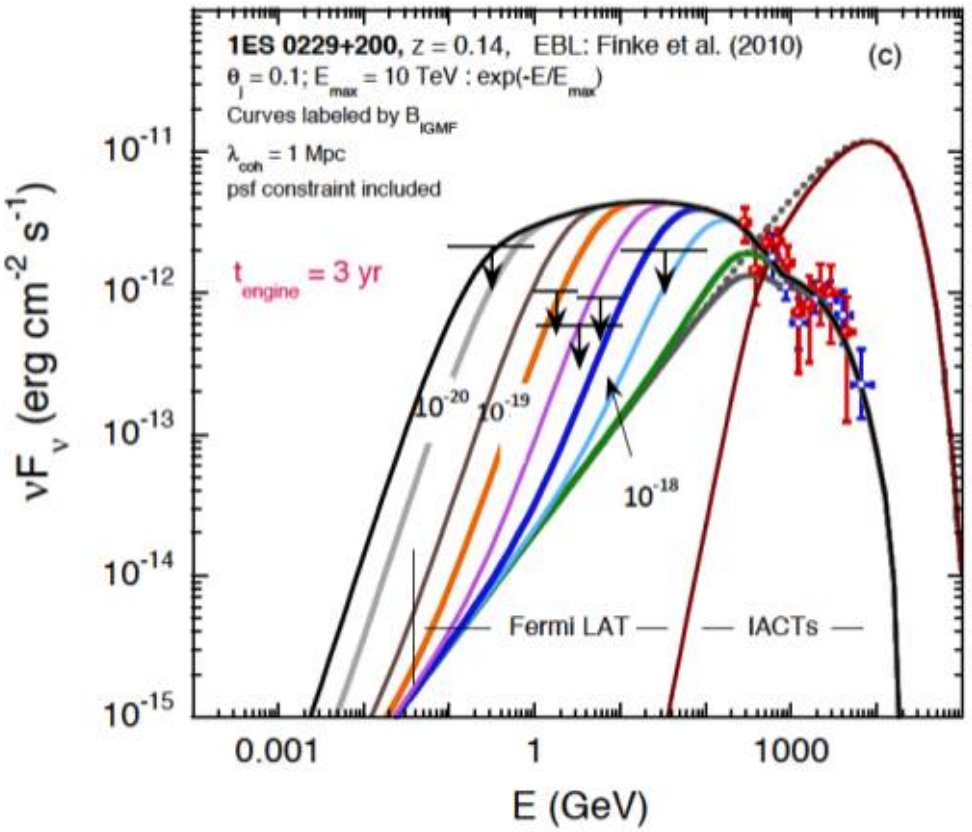
lower limits on IGMF from GeV/TeV data:

- *Neronov & Vovk*: B>3x10^-16 G
(persistent TeV emission over >10^6 years)
- *Dermer et al.*: B>10^-18 G
- *Taylor et al.* (astro-ph/1101.0932): B>10^-17 G
(persistent TeV emission over a few years)
- *Takahashi et al.* (astro-ph/1103.3835): B>10^-19.5
(from simultaneous GeV-TeV data)

=> need good continuous GeV/TeV data

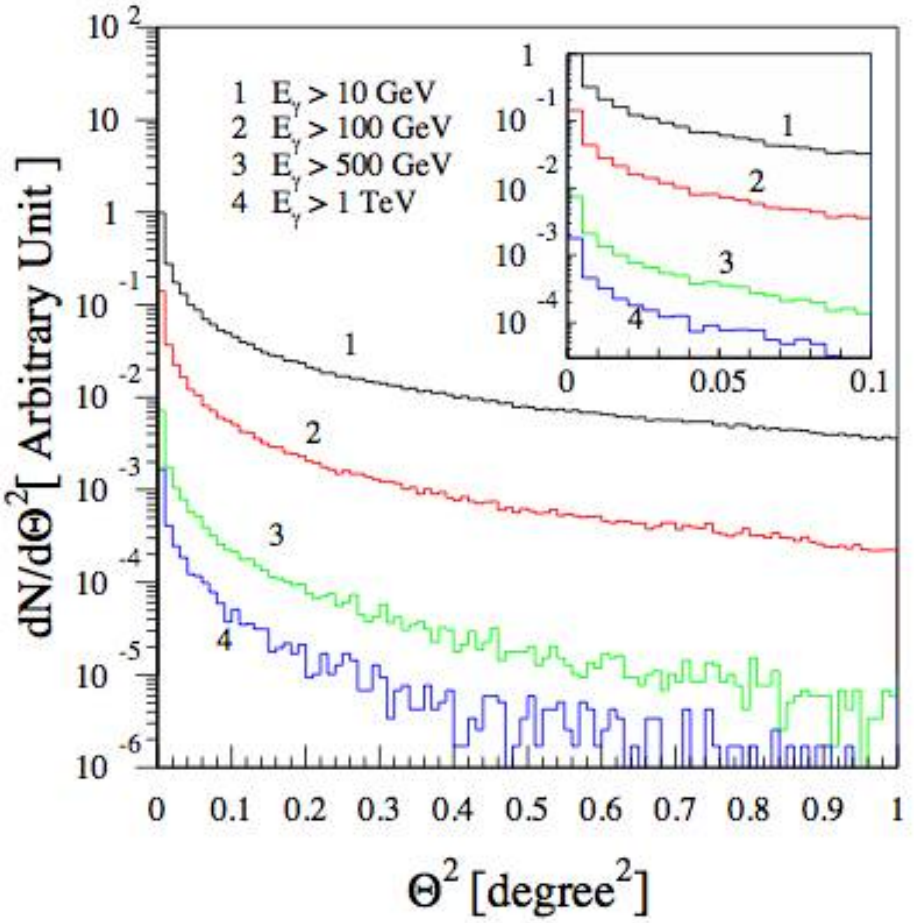
- secondary emission due to pair production on EBL + IC on CMB

- time delay introduced by diffusion in Intergalactic Magnetic Fields



Dermer et al., astro-ph/1011.6660

IGMF and pair halos



pair halo at z=0.129

Eungwanichayapant, Aharonian,
Int. J. of Mod. Ph. D 18 (2009) 911

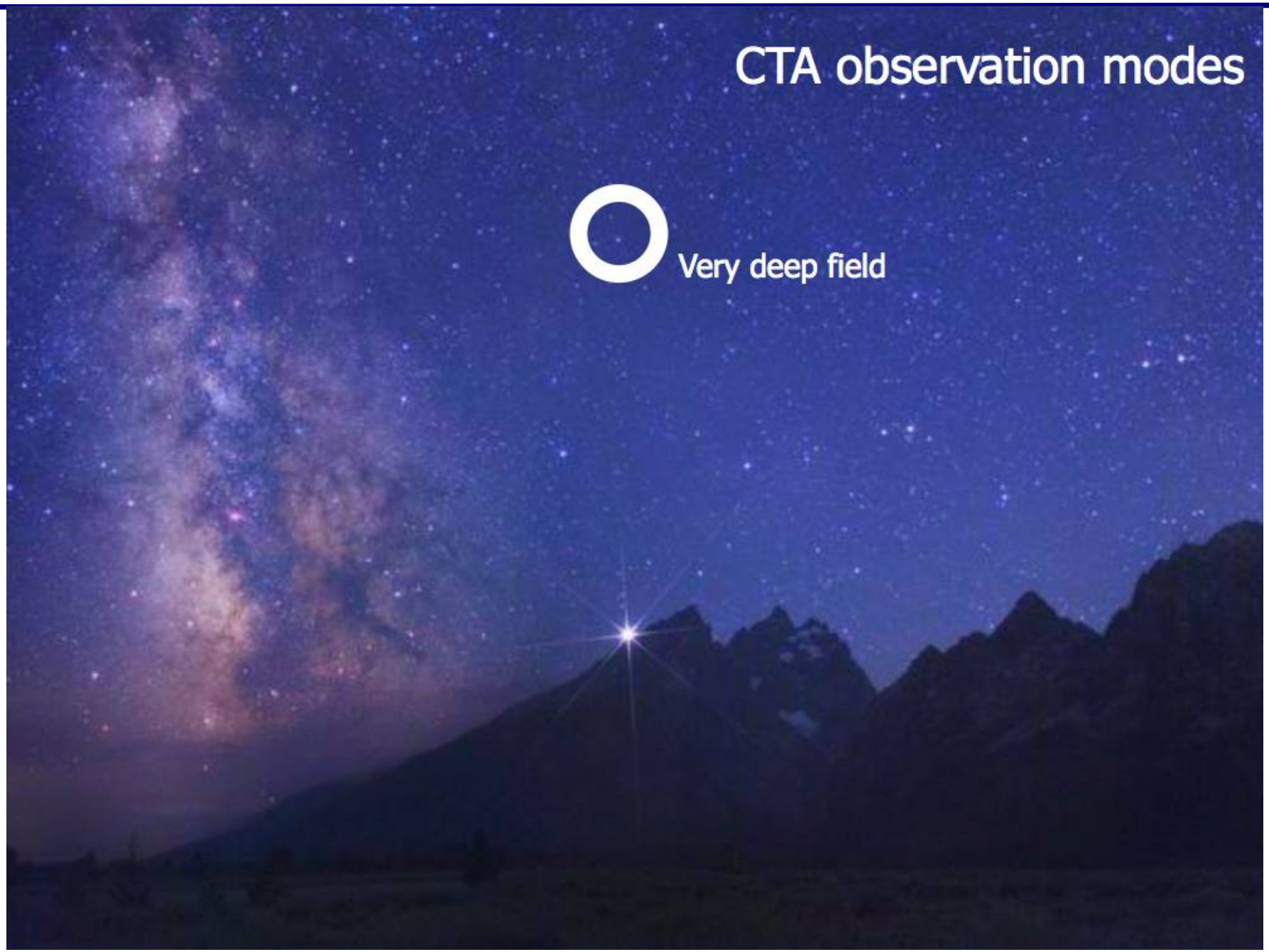
- The same processes can also lead to extended pair halos, if B high enough.

- need high sensitivity, large FoV, good control of background in GeV/TeV

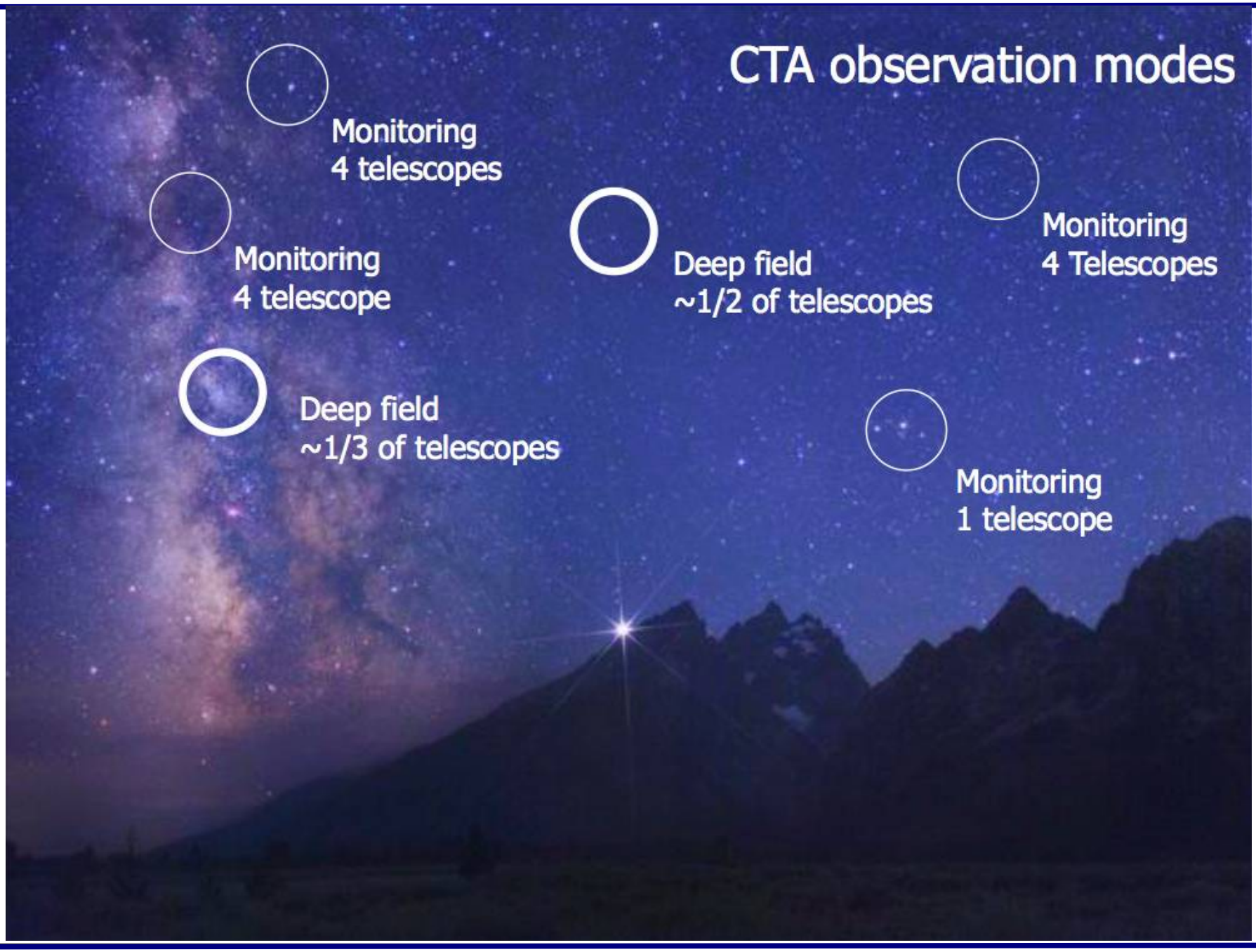
- no detection so far (ongoing study with VHE data: L. Fallon (for H.E.S.S.), PoS, Texas Symp. 2010)

=> prospects for CTA
(large FoV, high sensitivity)

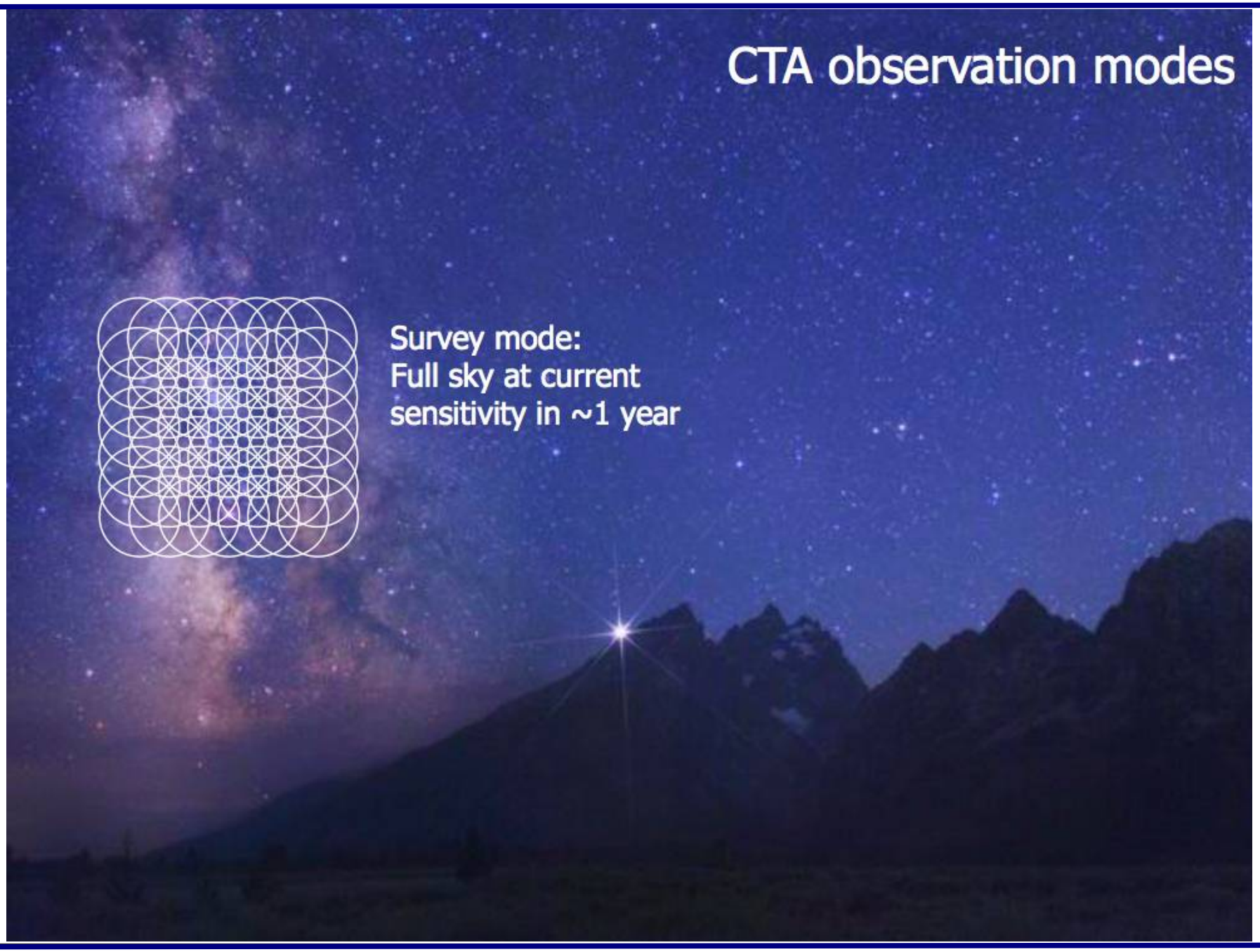
Different observation modes



Different observation modes

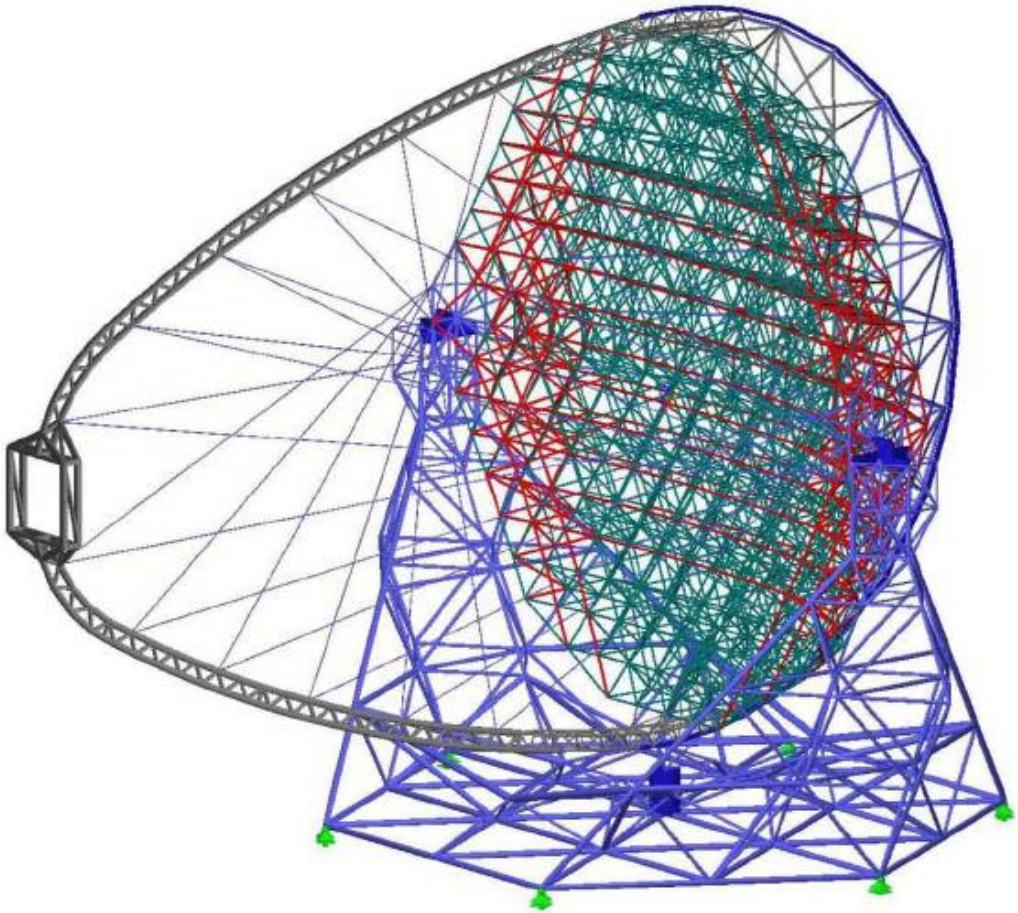


Different observation modes

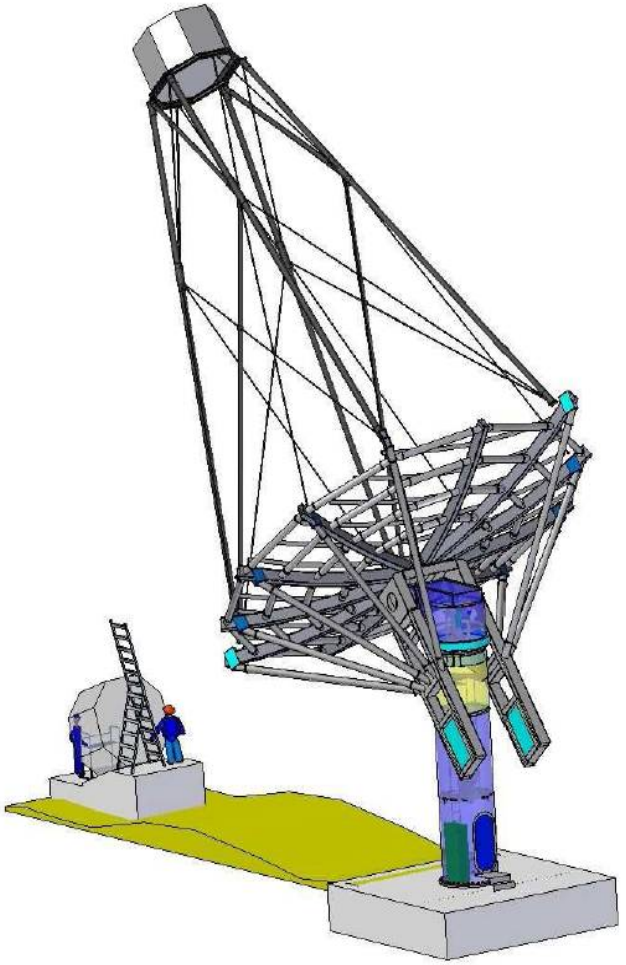


Telescopes for CTA

Large Size Telescopes (LST)
~4 (both sites ?)
diameter 24 m, FoV ~4-5 deg
(modified) Davies-Cotton optics
carbon fiber structure



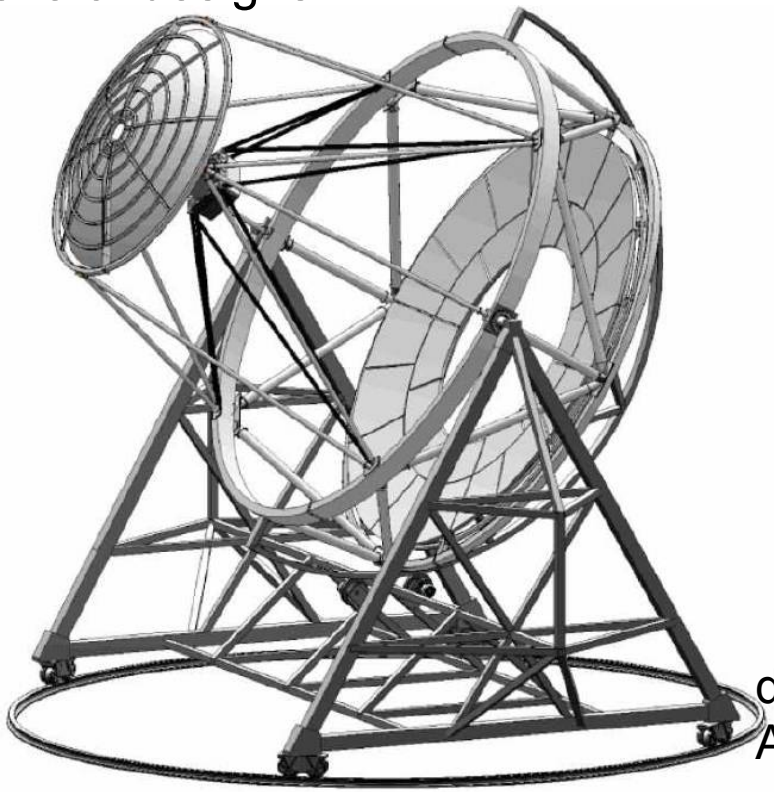
Medium Size Telescopes (MST)
~ 20 (both sites)
diameter 12 m, FoV ~6-8 deg
(modified) Davies-Cotton optics
several designs



Telescopes for CTA

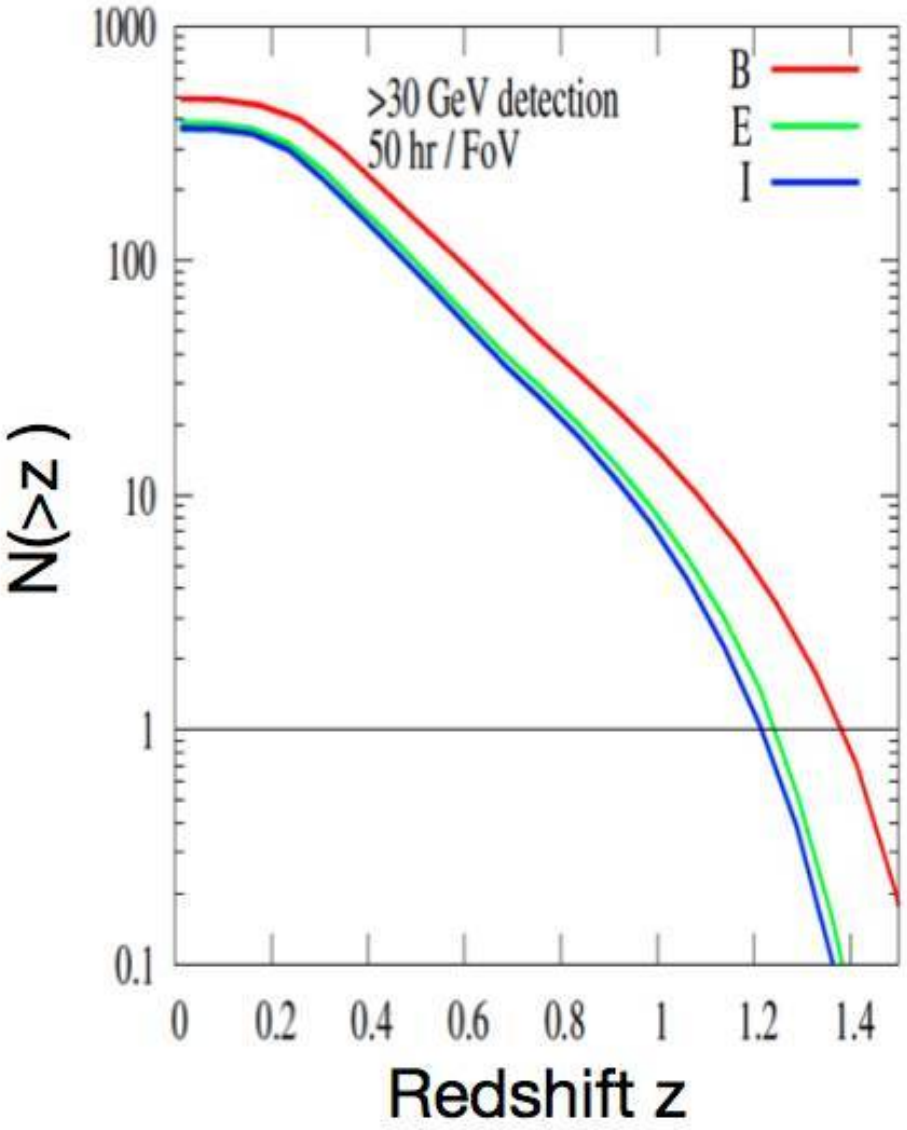
Schwarzschild-Couder Telescopes (SCT)
~36 (Southern array)
secondary optics; primary diameter ~10 m
FoV ~ 8 deg
high resolution imaging
small camera plate scale allows use
of SiPMs or MAPMTs
but optical system more complex
several designs

Small Size Telescopes (SST)
Davies-Cotton or Schwarzschild-Couder design
~30 (D-C) or 50+ (S-C)
(Southern array only ?)
Diameter ~7 m (D-C) or ~ 4m (S-C).
FoV ~ 8 - 10 deg
several designs



design: Argonne

Blazars at high redshift

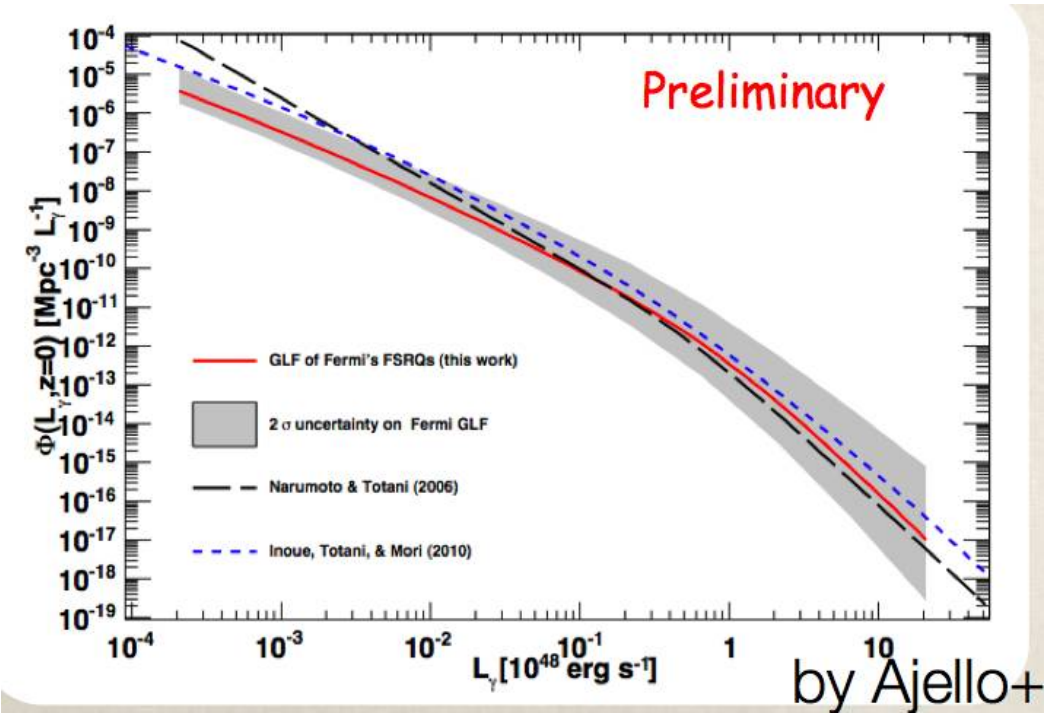


Y.Inoue, T.Totani, AGN Physics in the CTA Era

Predictions using the Gamma-ray luminosity function (GLF) by Inoue & Totani (2009)

GLF based on "blazar sequence" SED and AGN X-ray luminosity function (Ueda et al. 2003)

GLF in good agreement with EGRET and Fermi/LAT GLF for FSRQ.



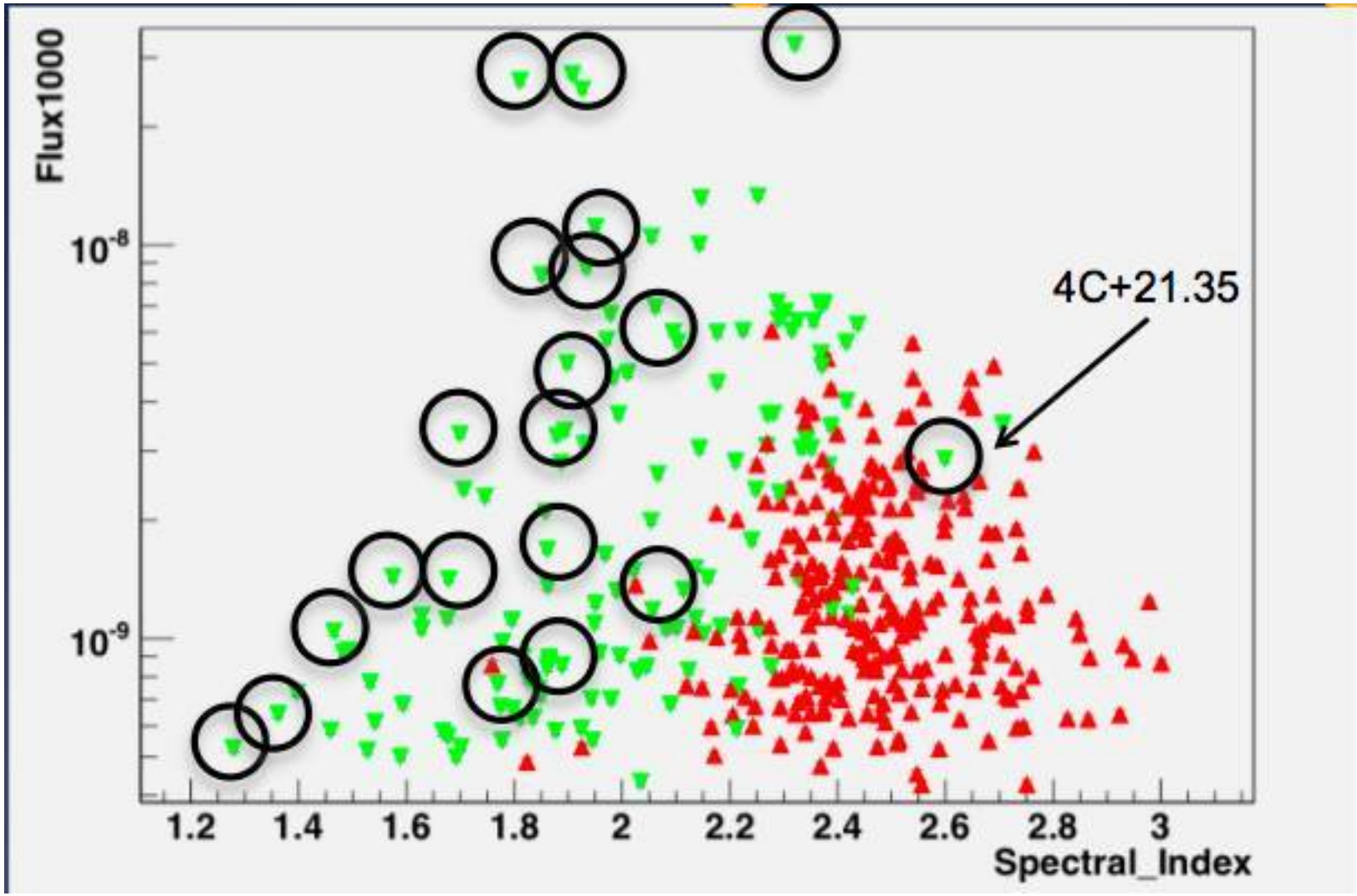
Fermi Extrapolations

Fermi AGN from **1 LAC** catalog (green + red)

Fermi AGN detectable with CTA in 50h

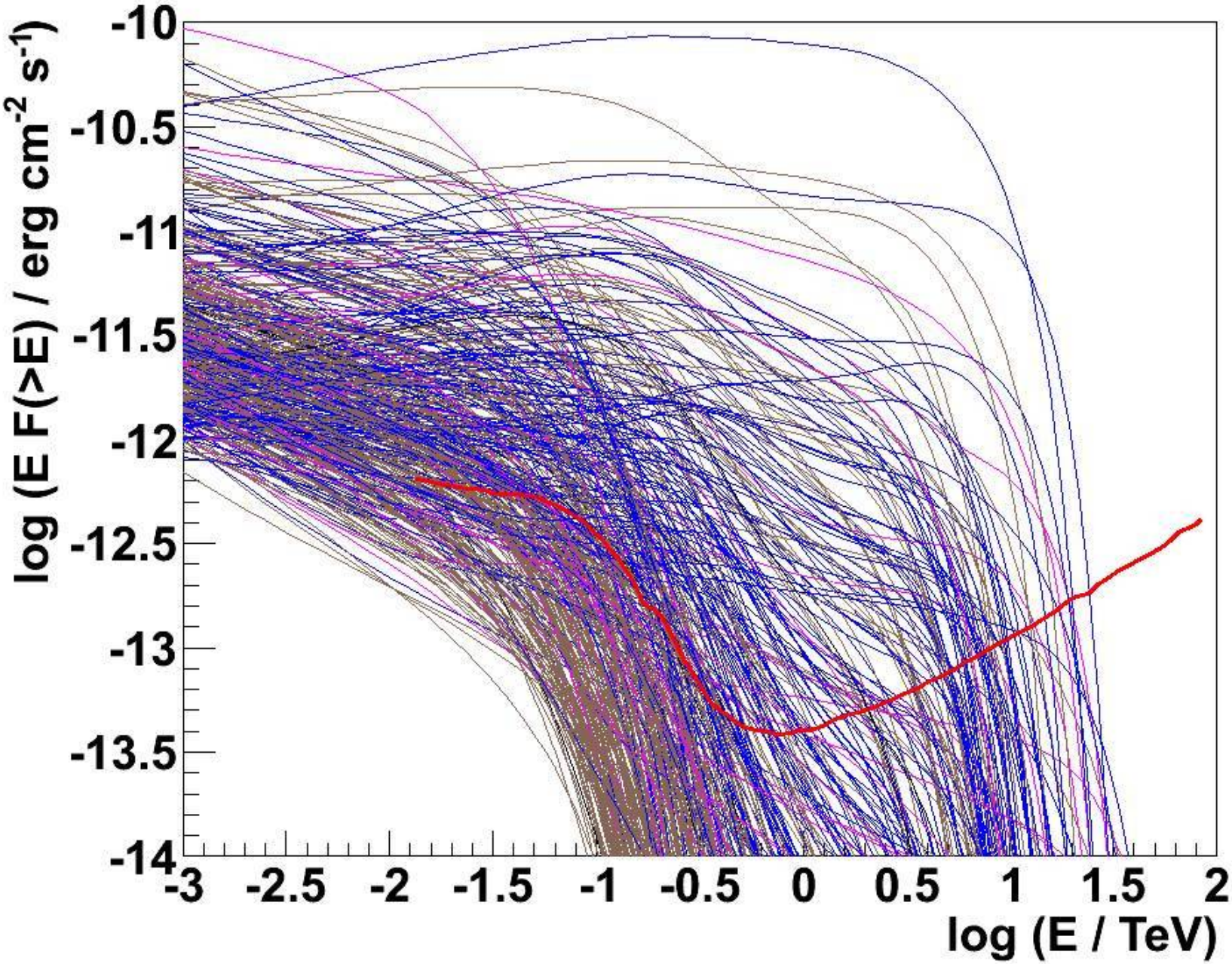
Circles: Blazars already detected at TeV

=> extension of the VHE blazar sample to lower fluxes and softer spectra



Mirabal, Hassan, Contreras, AGN Physics in the CTA Era

Fermi extrapolations



BL Lacs
FSRQ
other AGN
unknown type

CTA sensitivity (goal)